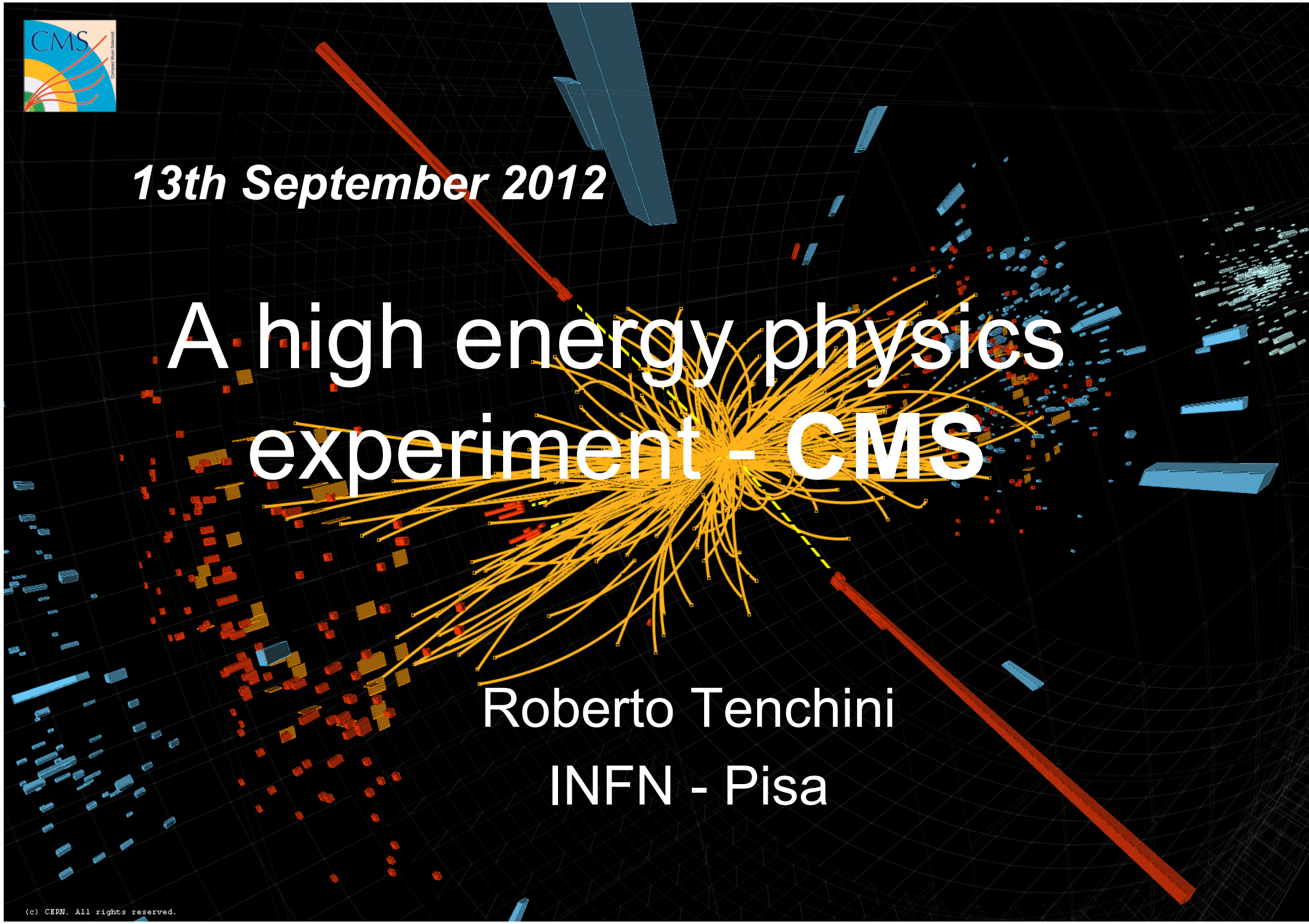


13th September 2012

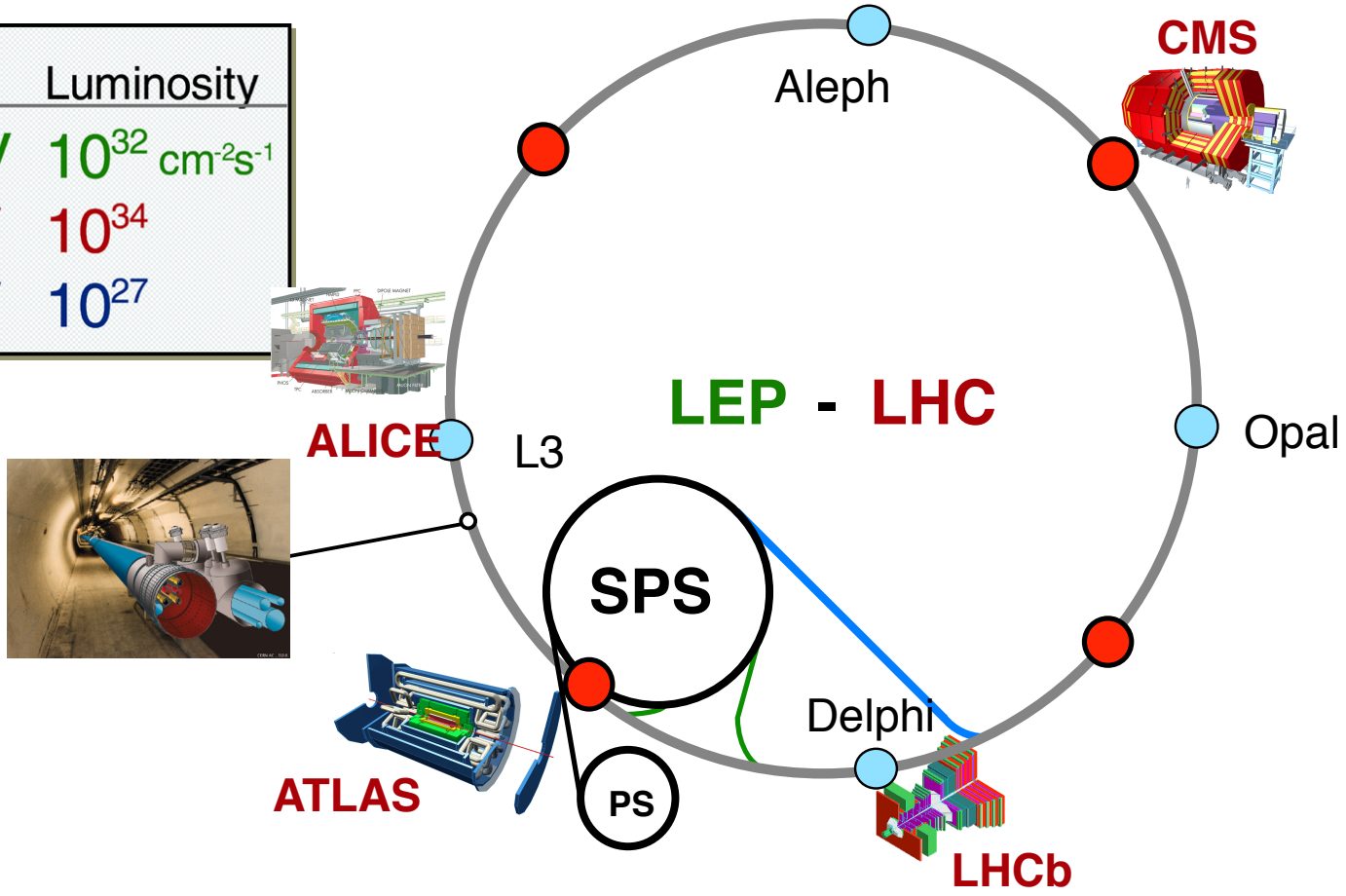
A high energy physics experiment - **CMS**

Roberto Tenchini

INFN - Pisa

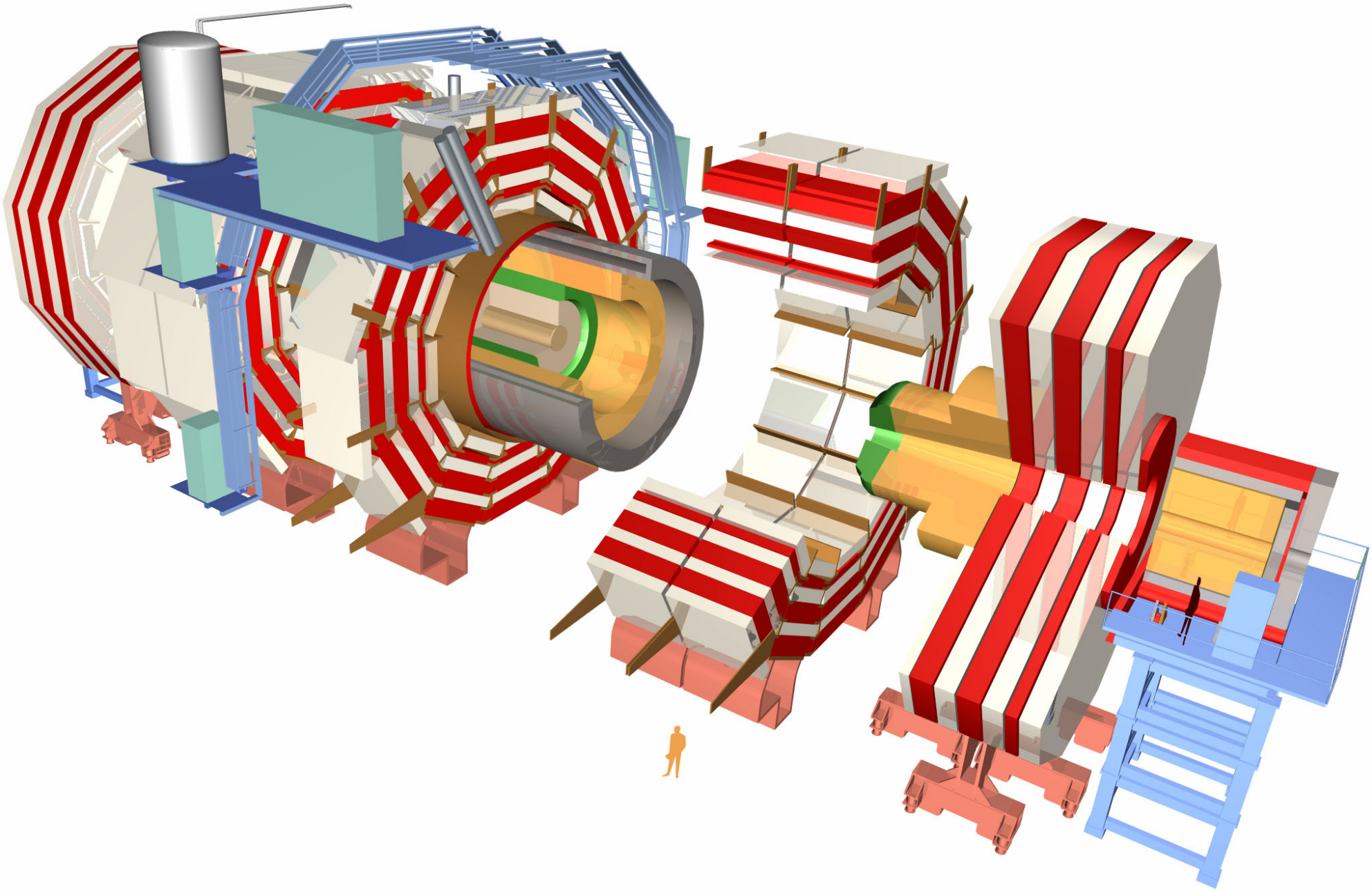
Experiments at the LHC

	Beams	Energy	Luminosity
LEP	e^+e^-	200 GeV	10^{32} $cm^{-2}s^{-1}$
LHC	p p	14 TeV	10^{34}
	$P_b P_b$	1312TeV	10^{27}



Experiments at LHC:
ATLAS A Toroidal LHC ApparatuS (proton-proton collisions)
CMS Compact Muon Solenoid (proton-proton collisions)
ALICE A Large Ion Collider Experiment (Ion-ion collisions)
LHCb (Study of CP violation in B-meson)

The Compact Muon Solenoid (CMS)

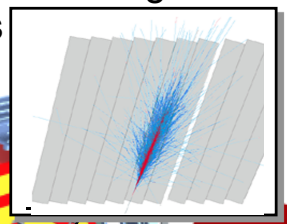


The Compact Muon Solenoid (CMS)

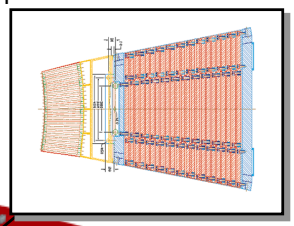
SUPERCONDUCTING COIL

CALORIMETERS

ECAL Scintillating $PbWO_4$ Crystals



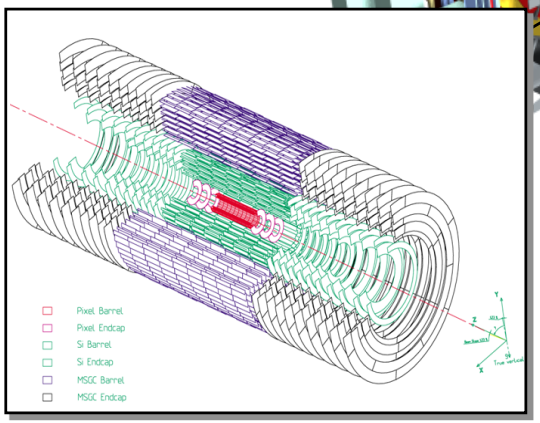
HCAL Plastic scintillator brass sandwich



Total weight : 12,500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla

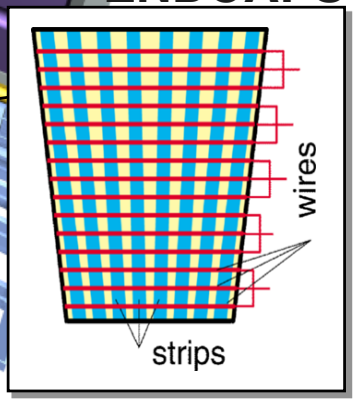
IRON YOKE

TRACKERs

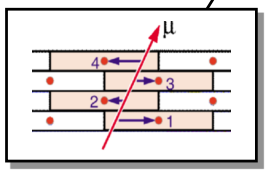


Silicon Microstrips
Pixels

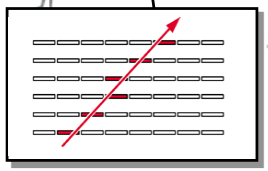
MUON ENDCAPS



MUON BARREL



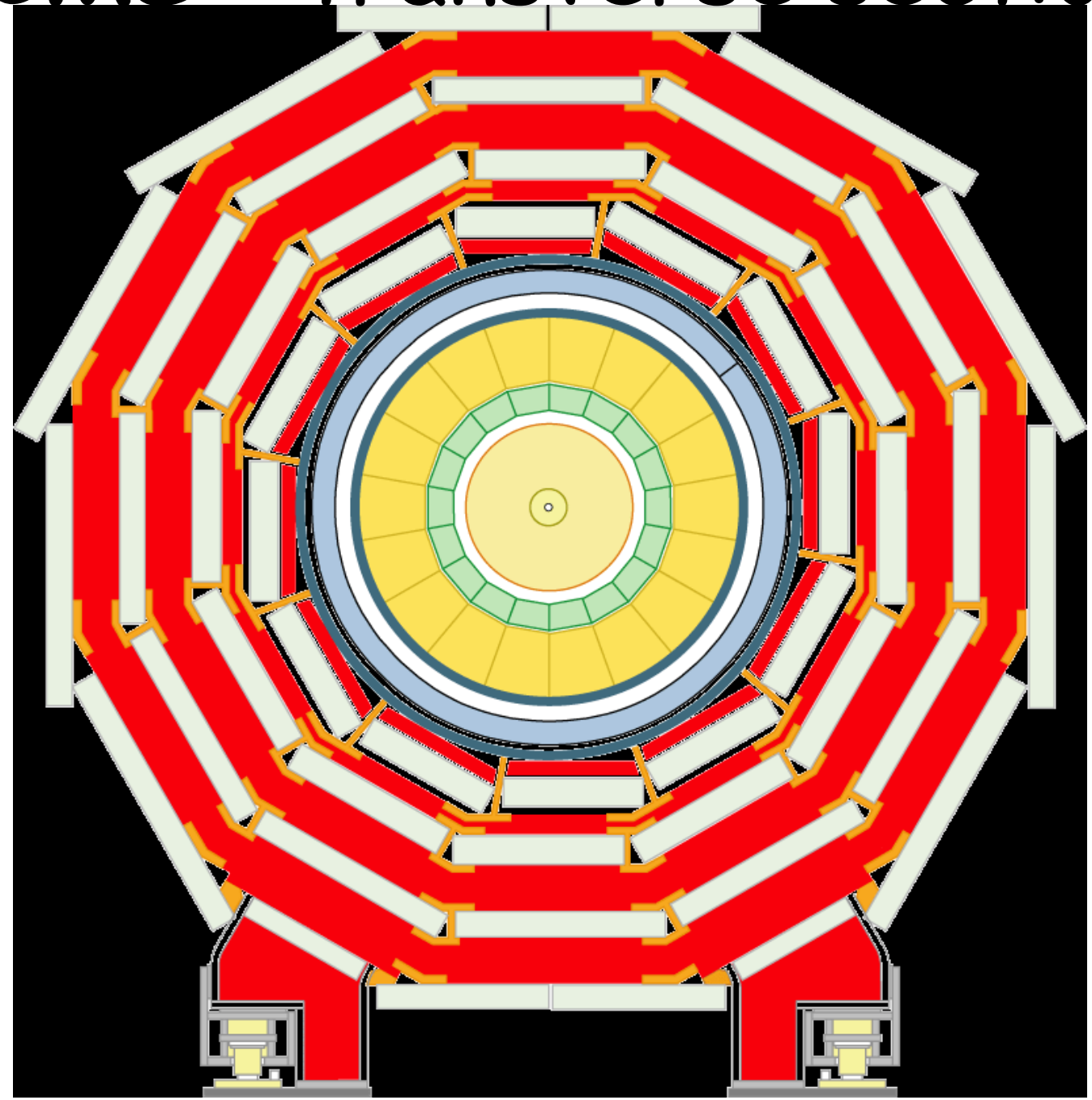
Drift Tube Chambers (**DT**)

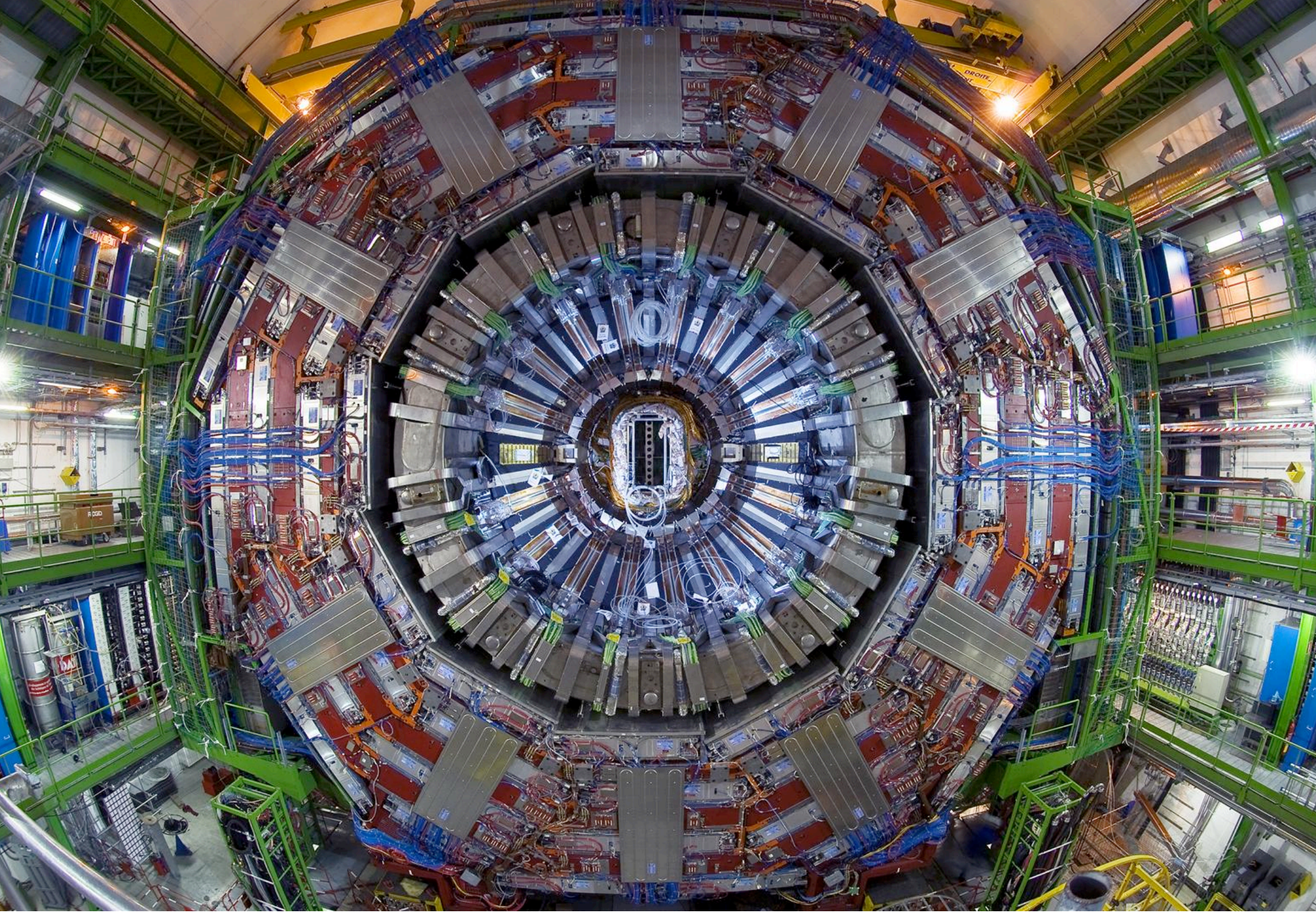


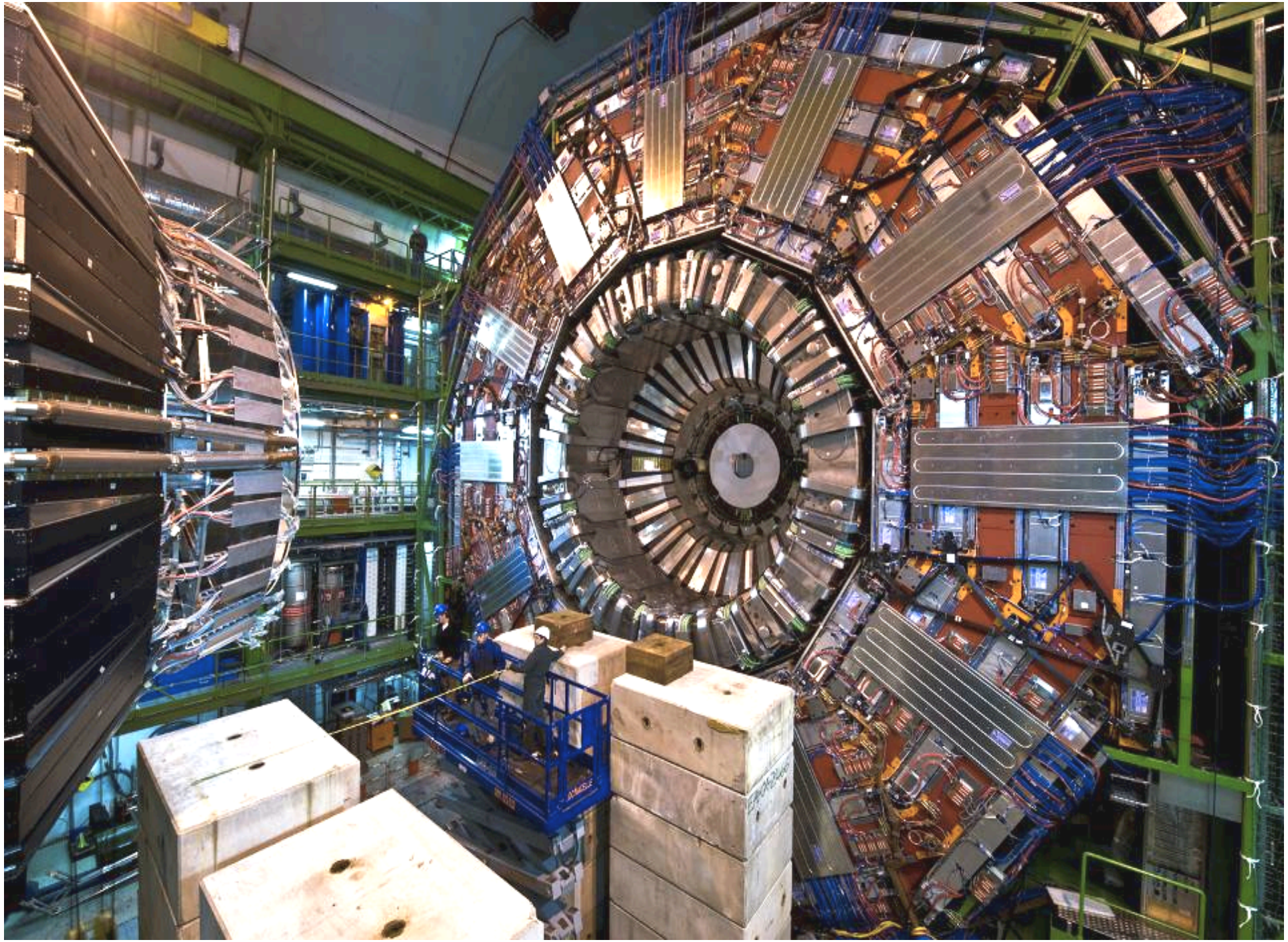
Resistive Plate Chambers (**RPC**)

Cathode Strip Chambers (**CSC**)
Resistive Plate Chambers (**RPC**)

CMS - transverse section







Constraints on LHC detectors

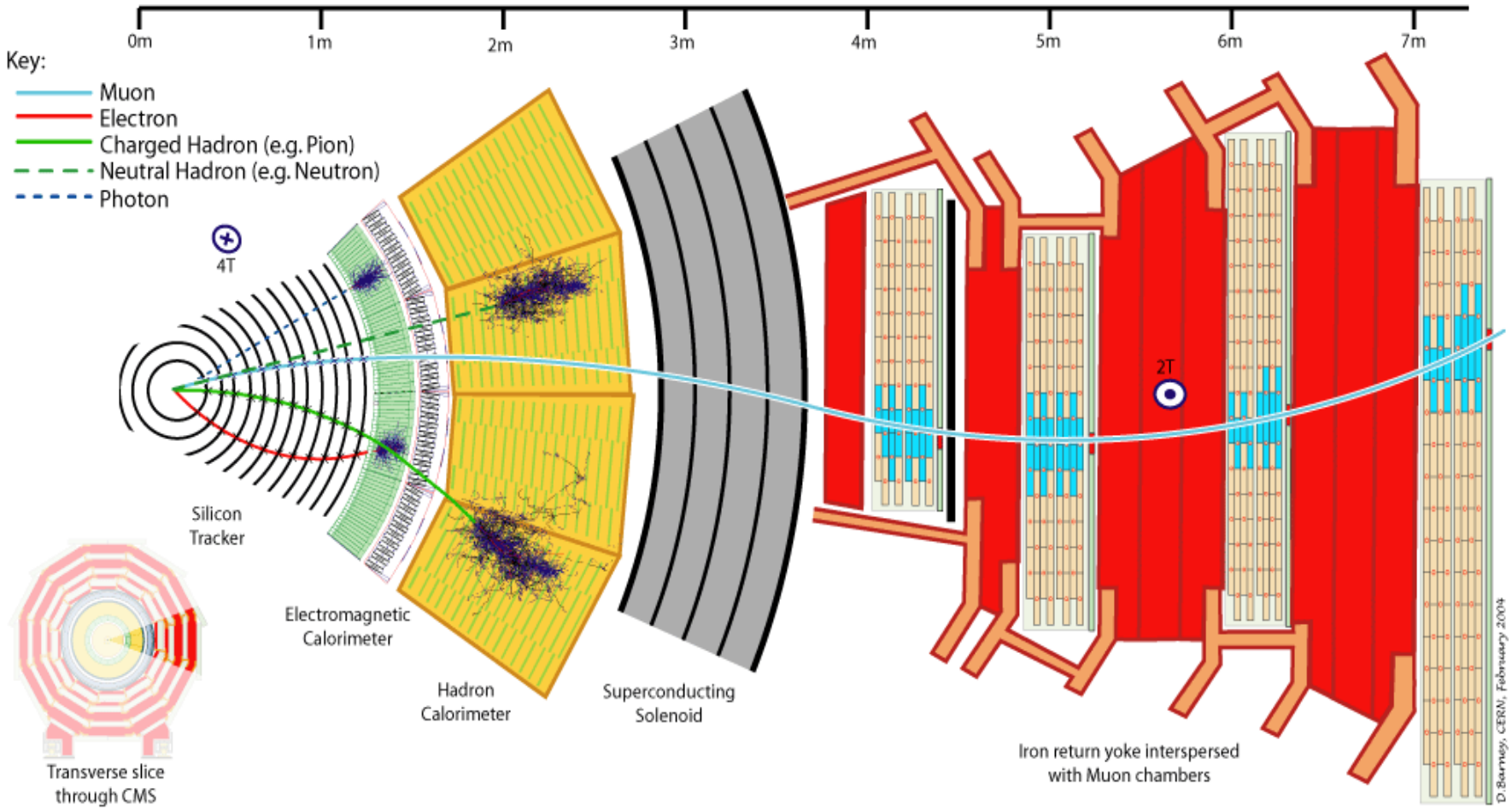
- Fast response
  - challenging readout electronics
- Granularity
  - large number of electronic channels
  - high cost
- High flux of particles from pp collisions → high radiation environment, e.g. in forward calorimeters:
  - -up to 10^{17} n/cm^2 in 10 years of operation
  - -up to 10^7 Gy
  - radiation hardness

→ <u>... An still maintain excellent physics performance</u>

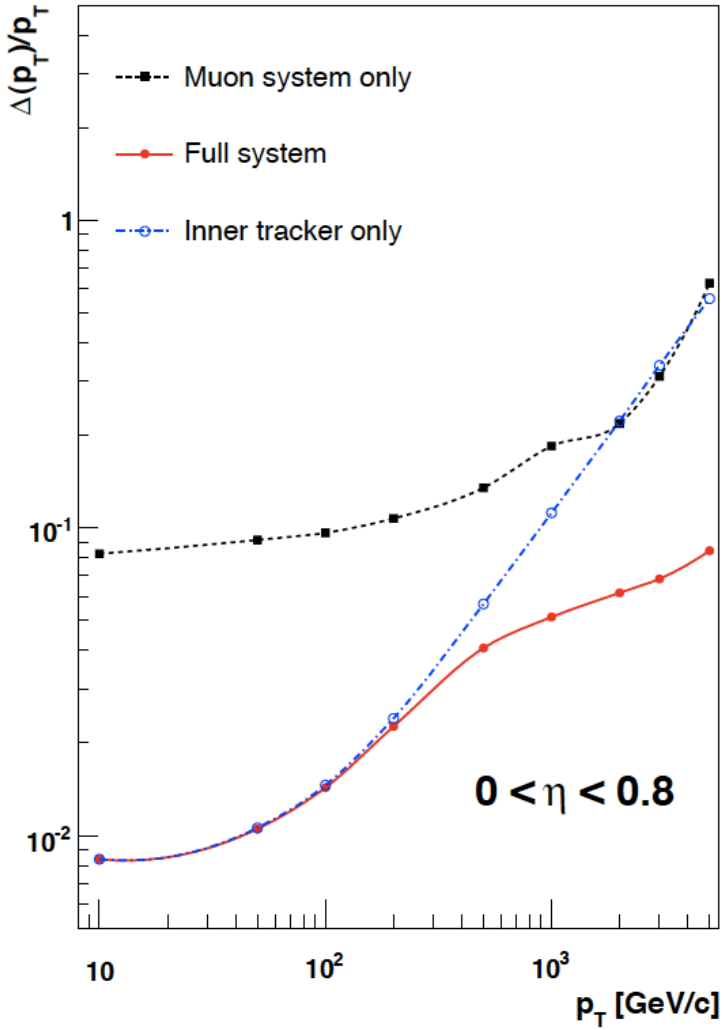
Main Physics Requirements of a General Purpose Apparatus

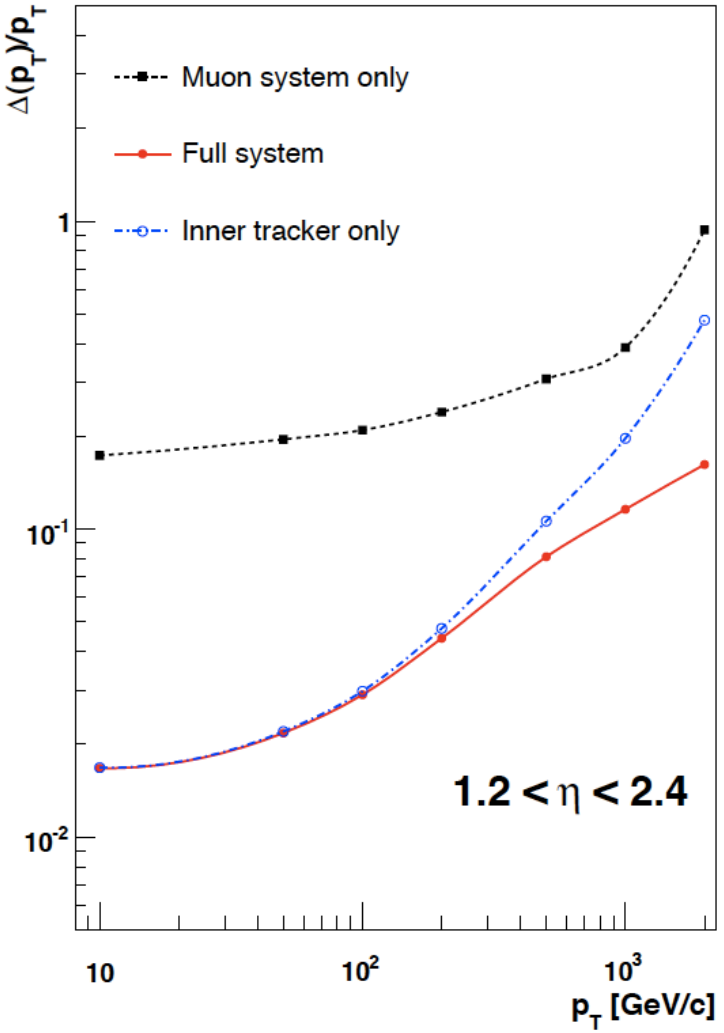
- Measure **momentum of charged tracks**
- Measure **energy of photons** and **neutral hadrons**
- Identify **electrons** and **muons**
- Reconstruct complex objects (**jets**, **taus**)
- Hermeticity (identify the presence of missing particles, e.g. **neutrini**)
- Important additions: reconstruction of long lived-particles, pion-kaon-proton separation, etc.

Particles through a CMS slice



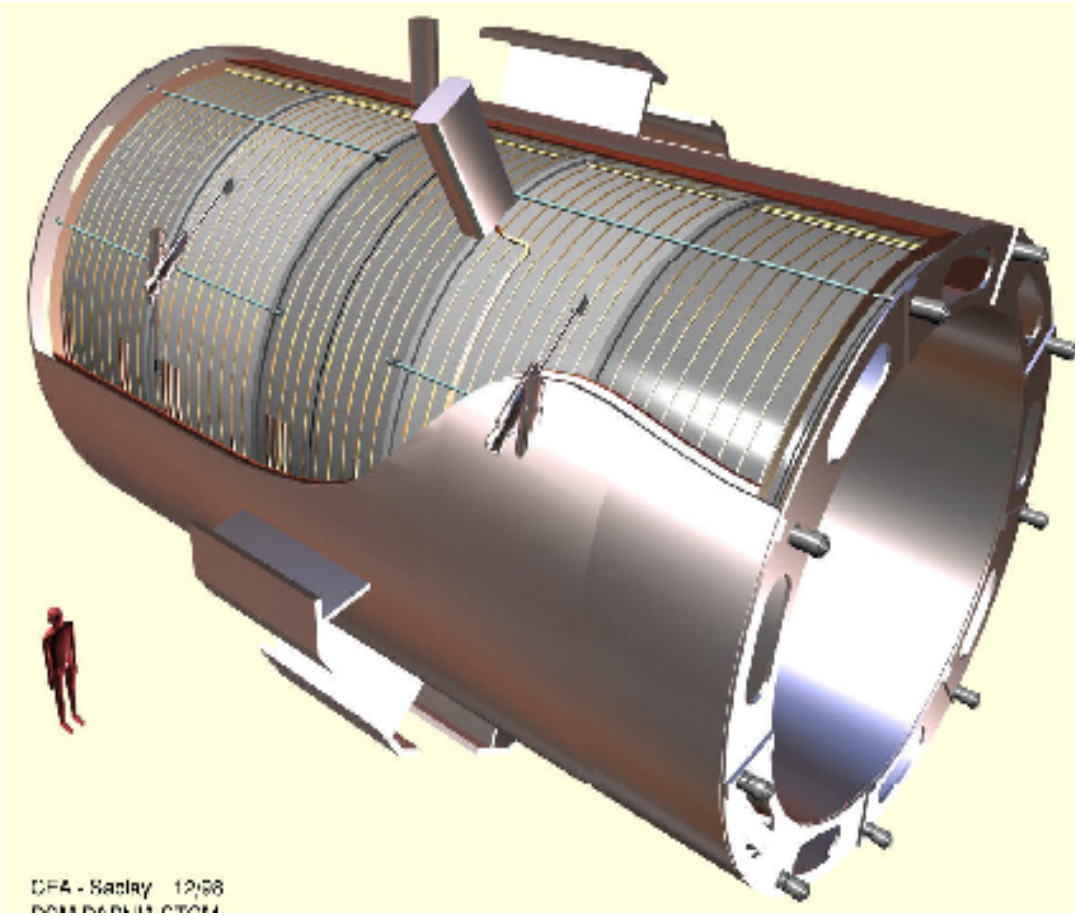
Transverse momentum resolution





The CMS solenoid

- Basic goal: measure 1 TeV muons with 10% resolution →B=4T
- B=μ_0nI; @2168 turns/m (4 layers) → I=20kA (SuperConducting Cable)
- Challenges: 4-layer winding to carry enough I, design of reinforced superC cable
- The superconductor chosen is Niobium Titanium (NbTi) wrapped with copper – needs to be cooled to ~4K
- Huge dimensions: 6m inner diameter x 12.5m lenght (built in 5 modules)

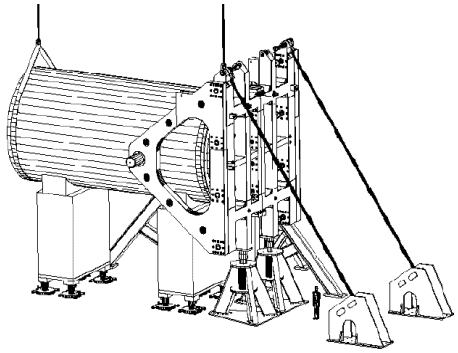


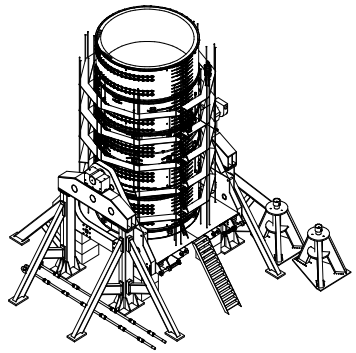
$$\frac{\Delta p}{p} \propto \frac{p}{qBL^2}$$

CMS Magnet: Cold Mass at surface

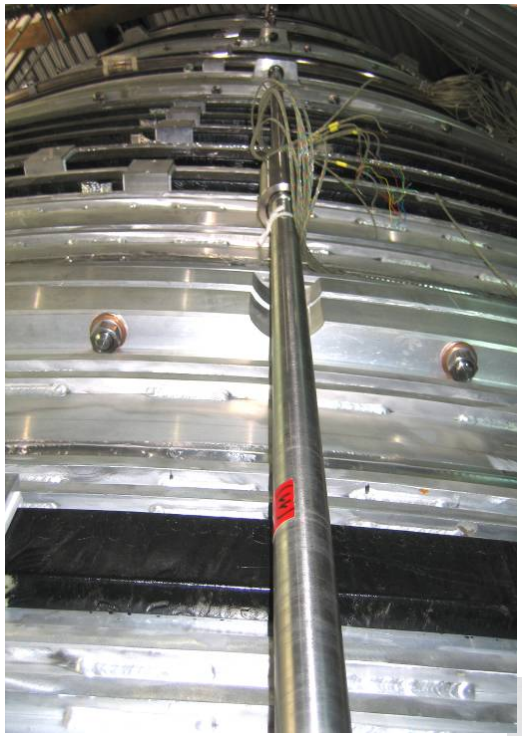
- **1st Mar 2005**: Completion of Cold-Mass.

Magnet turned on
August 2005

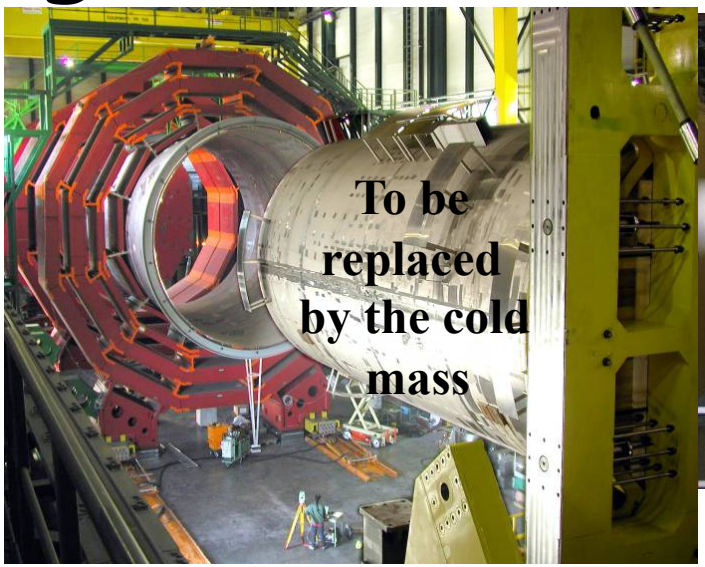




Magnet Construction



- All modules in series with instrumentation
- Insulation >50Mohms
- Leak Tested



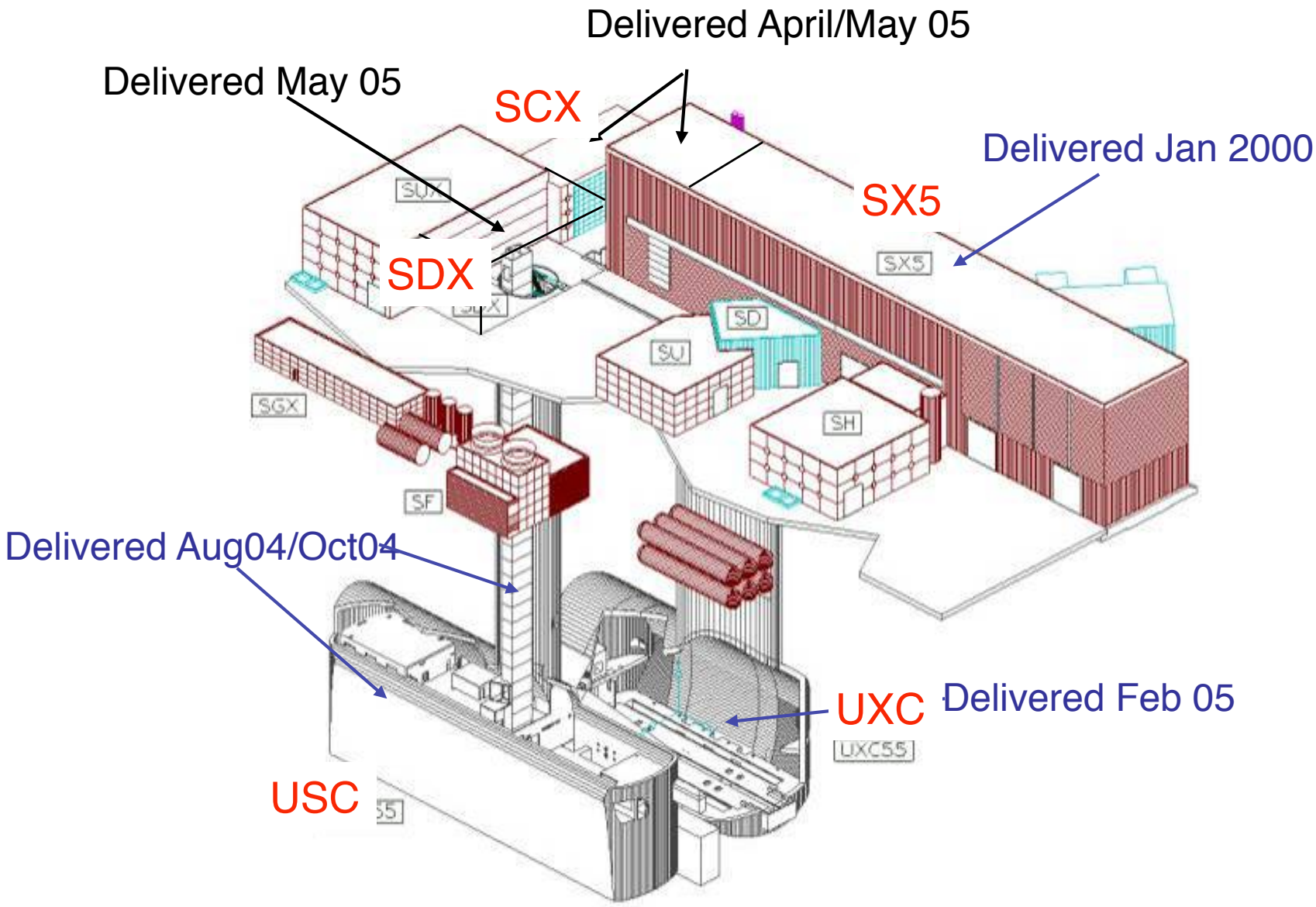
Swivelling in Aug 05

20 kA power converter tested

USC5 20 kA bus bars pushed through pillar wall

Dump resistors connected

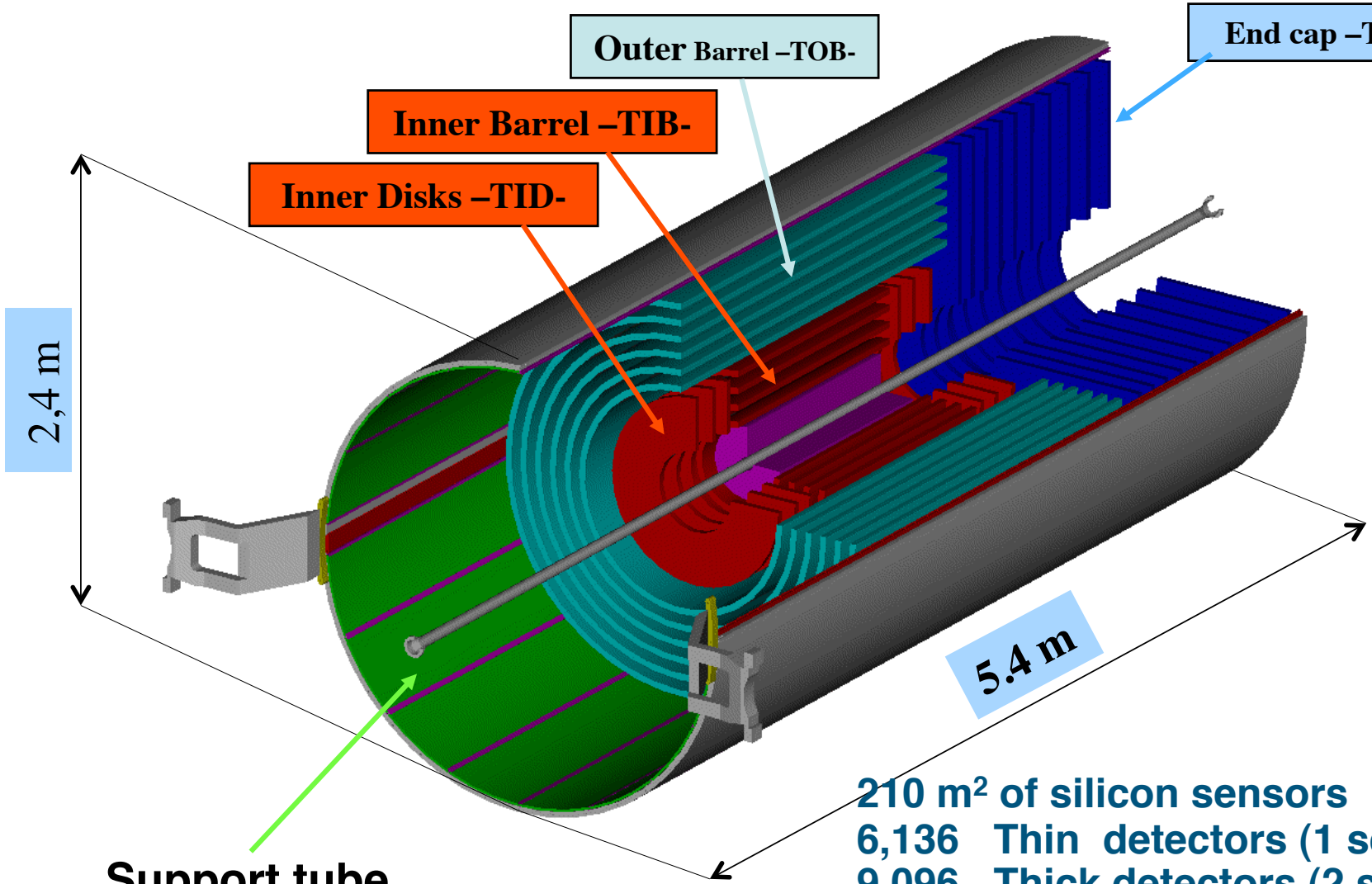
Civil Engineering Overview



UXC/USC5: CMS caverns

Delivered to the experiment
February 1st 2005.

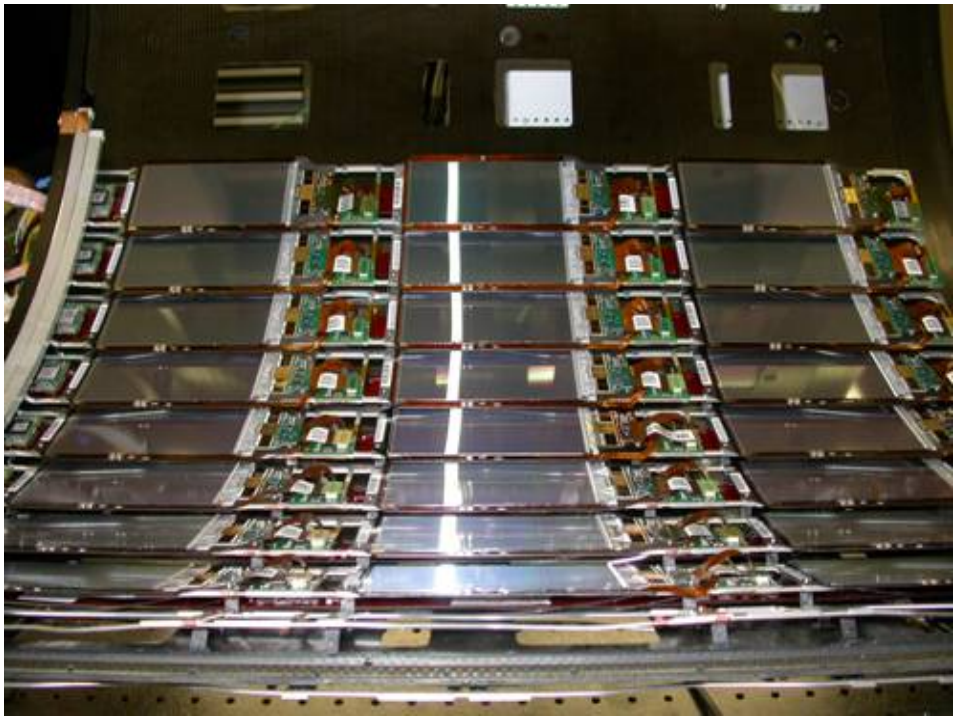
Silicon Strip Tracker



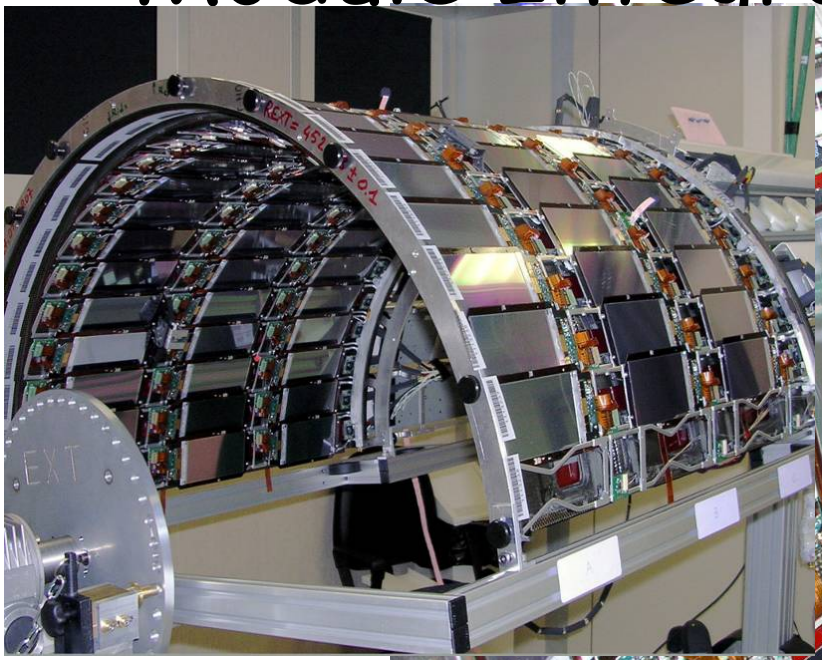
Support tube
And termal screen (-10 C^0)

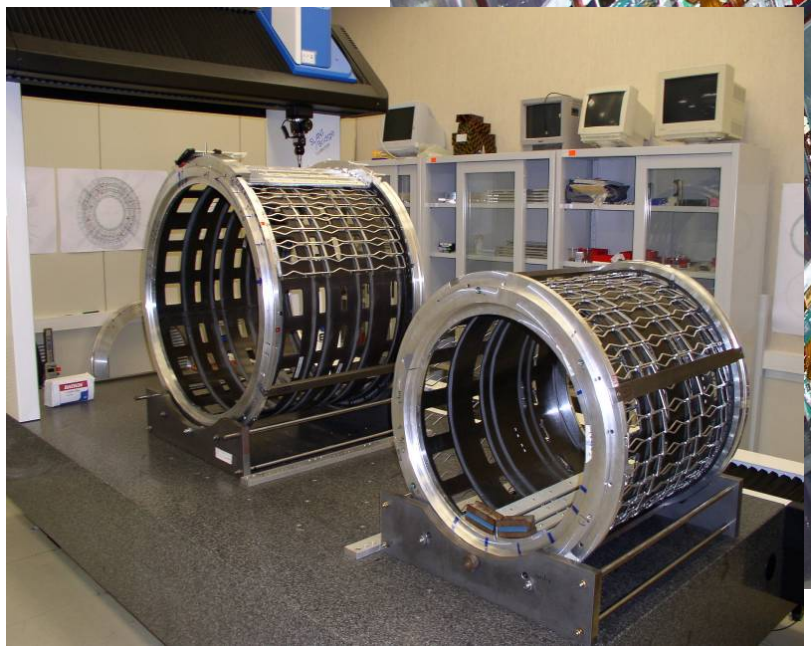
210 m^2 of silicon sensors
6,136 Thin detectors (1 sensor)
9,096 Thick detectors (2 sensors)
9,648,128 electronics channels

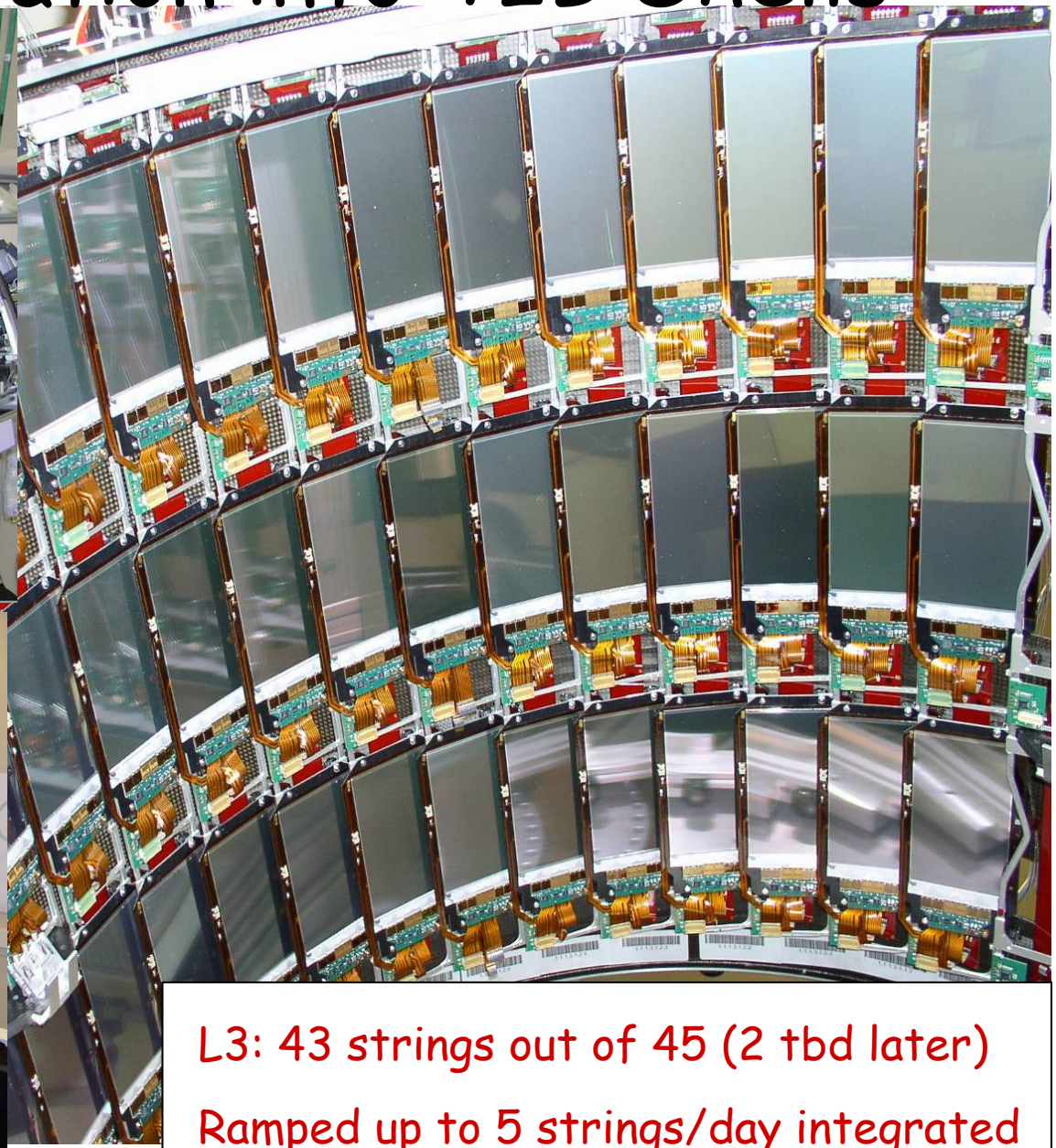
Tracker during construction



Module Integration into TIB Shells



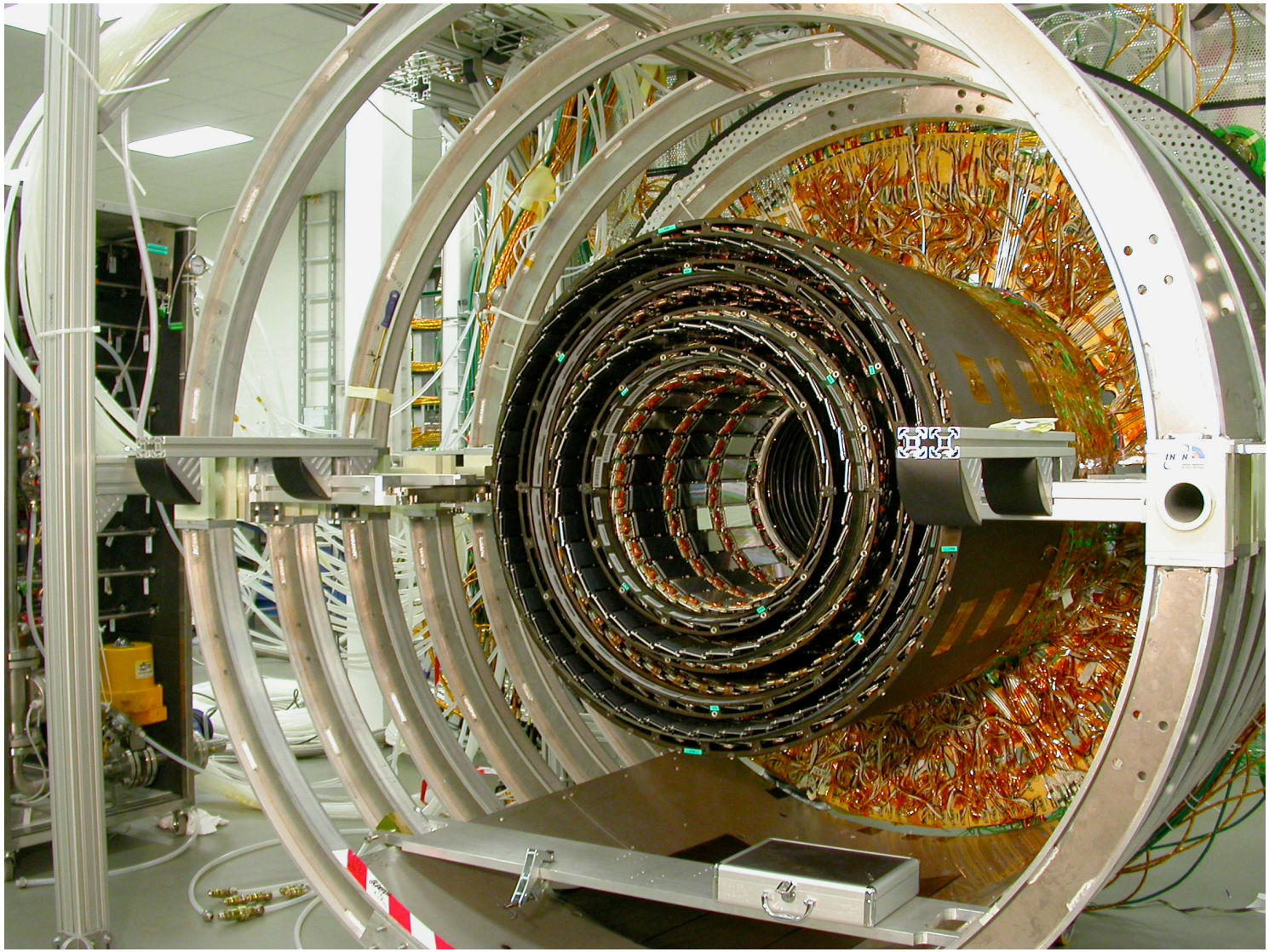




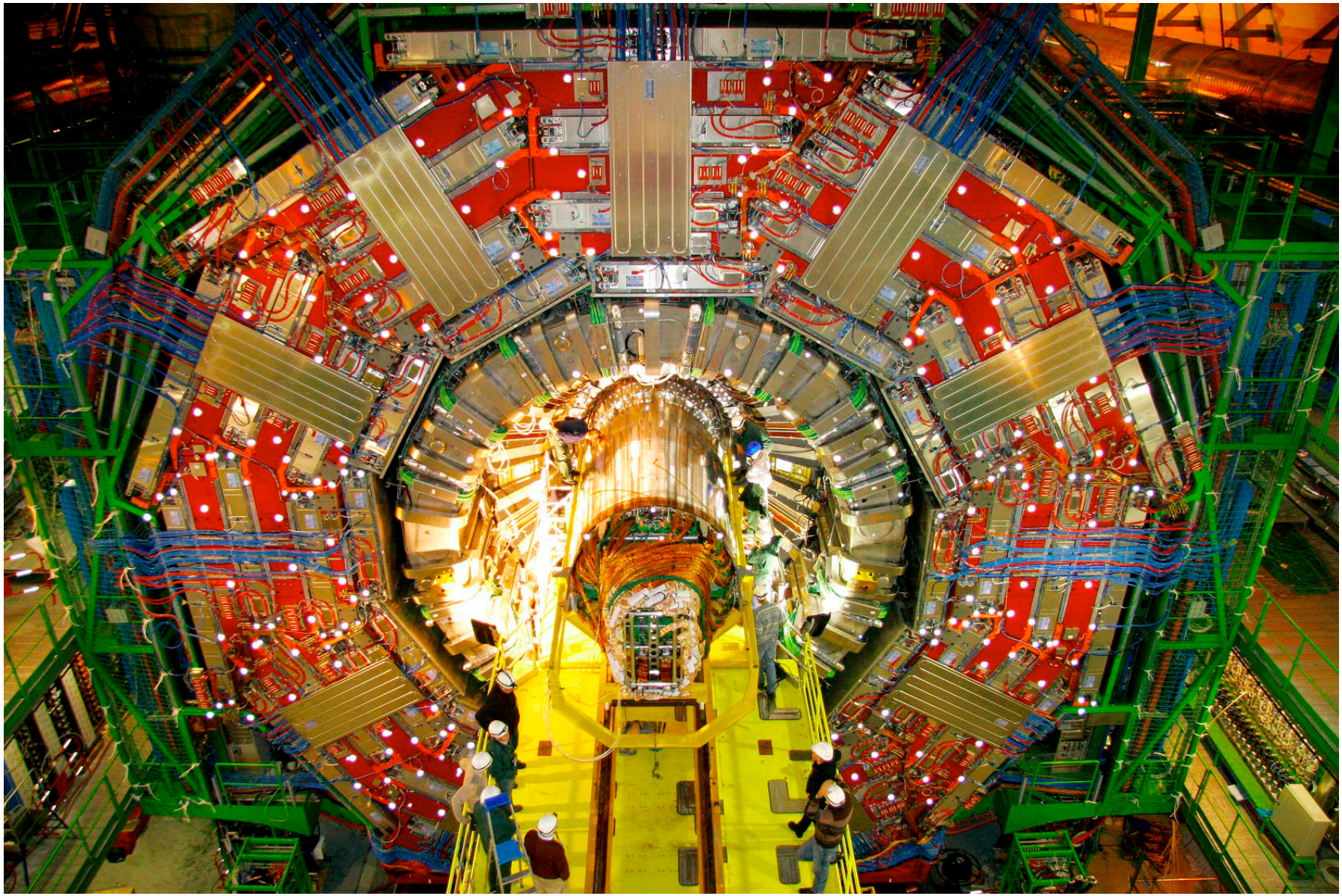
L3: 43 strings out of 45 (2 tbd later)

Ramped up to 5 strings/day integrated

Tracker inner barrel completed



Tracker insertion in CMS



Pixel detector

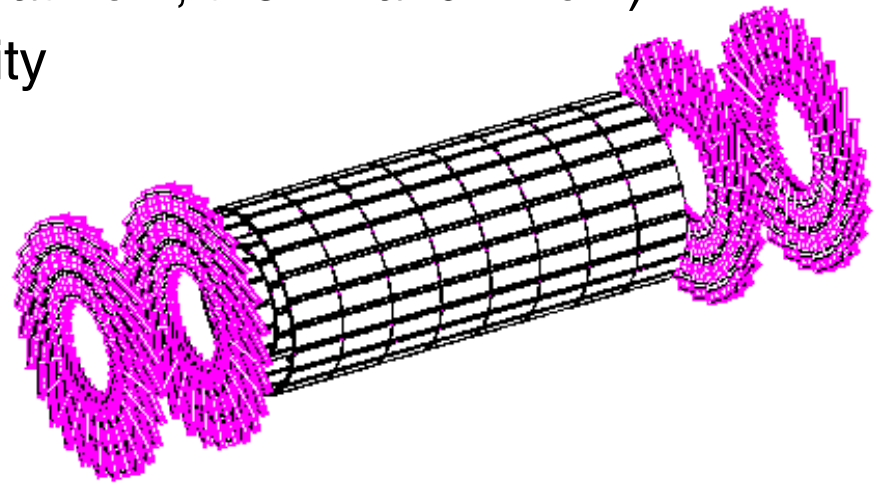
Very close to beam pipe (first point at 4cm, then 7 and 11 cm)

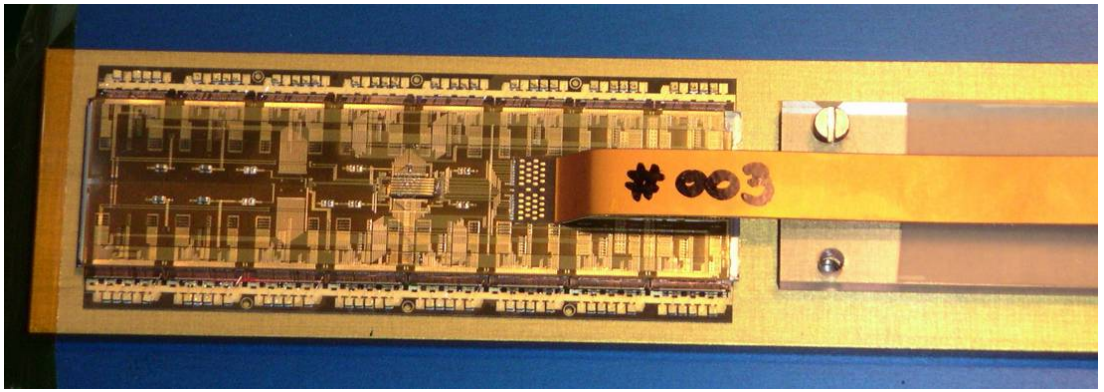
Different scenario for High luminosity

Small pixel size (150μm).

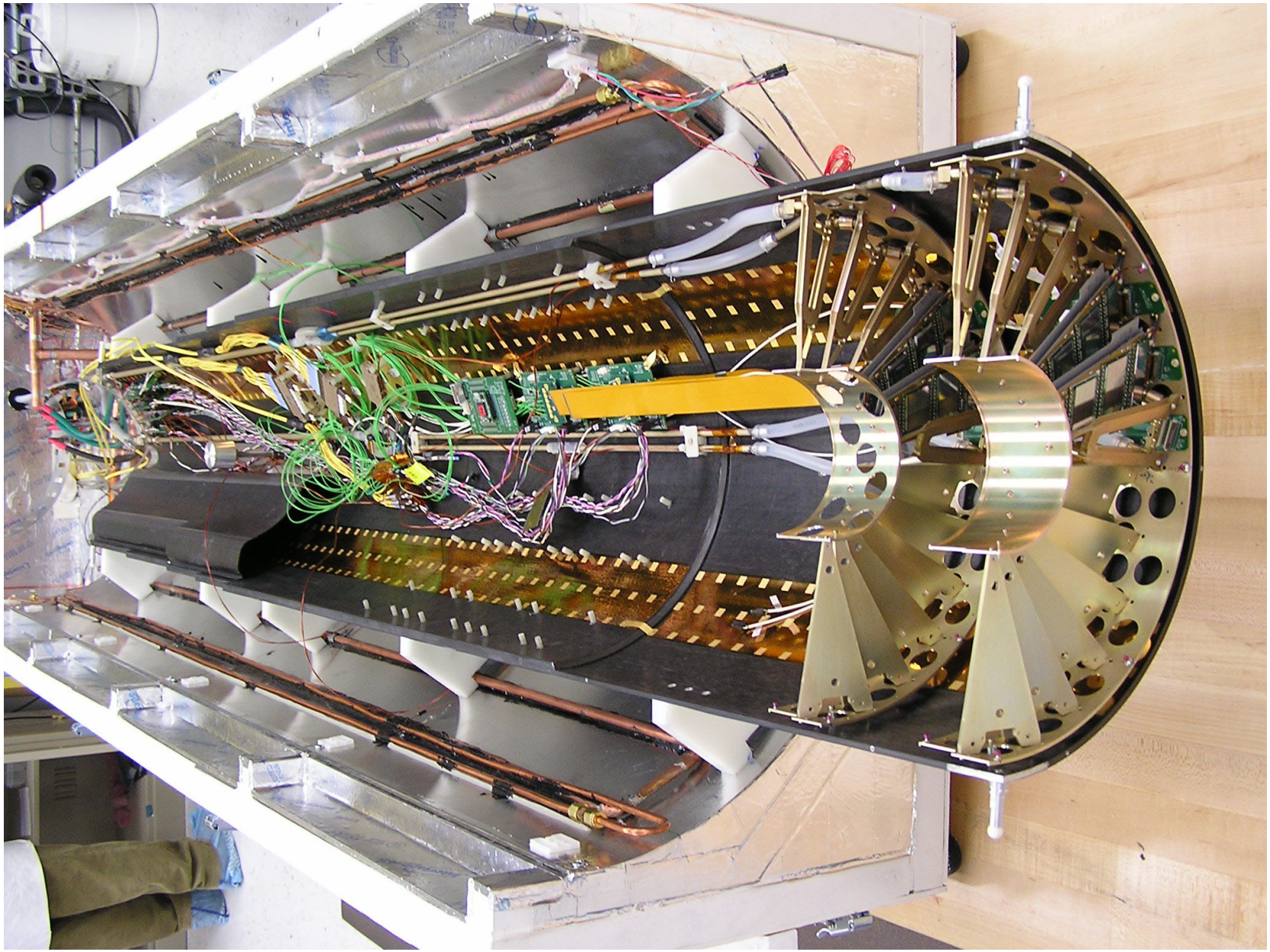
Occupancy: 10^{-4}.

Resolution: ~20μm.



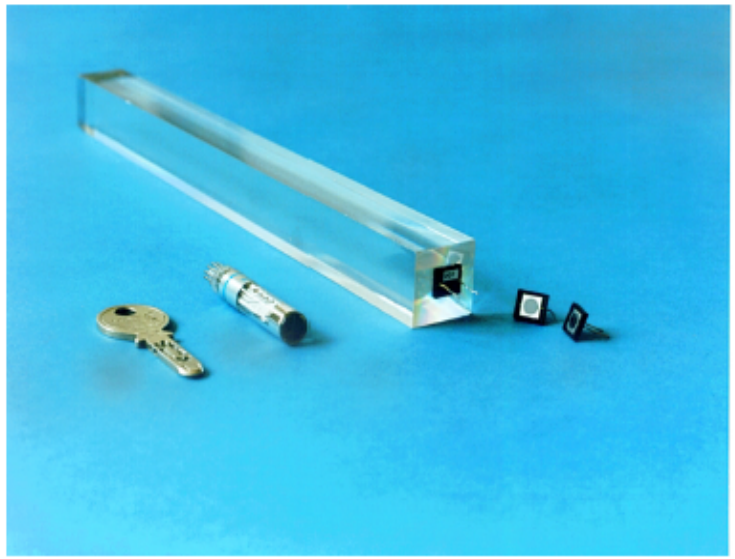


Pixel detector



ECAL

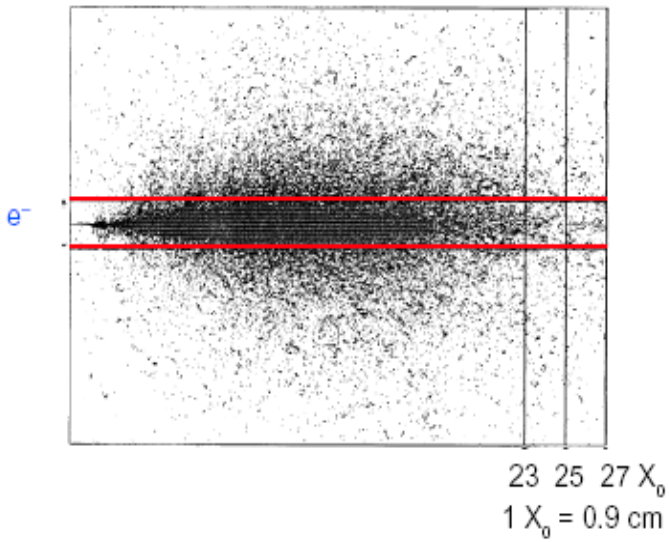
- 75.000 lead tungstate crystals
  - compact
  - fast (95% light emitted in 25ns)
  - highly granular (2.19cm Moliere rad)



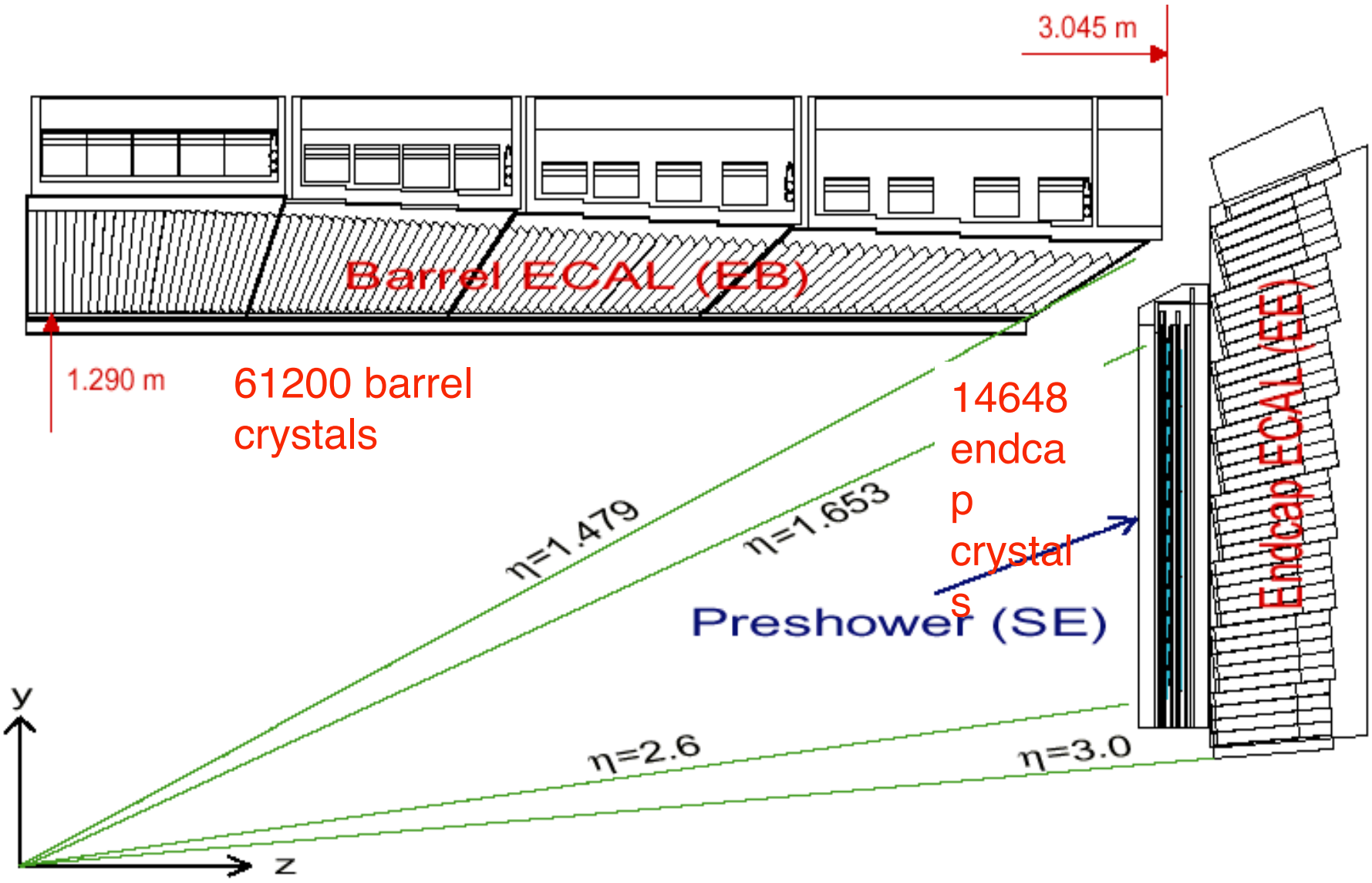
Readout with
- Avalanche PhotoDiodes (barrel)
- Vacuum Phototriodes (endcap)

Excellent energy resolution

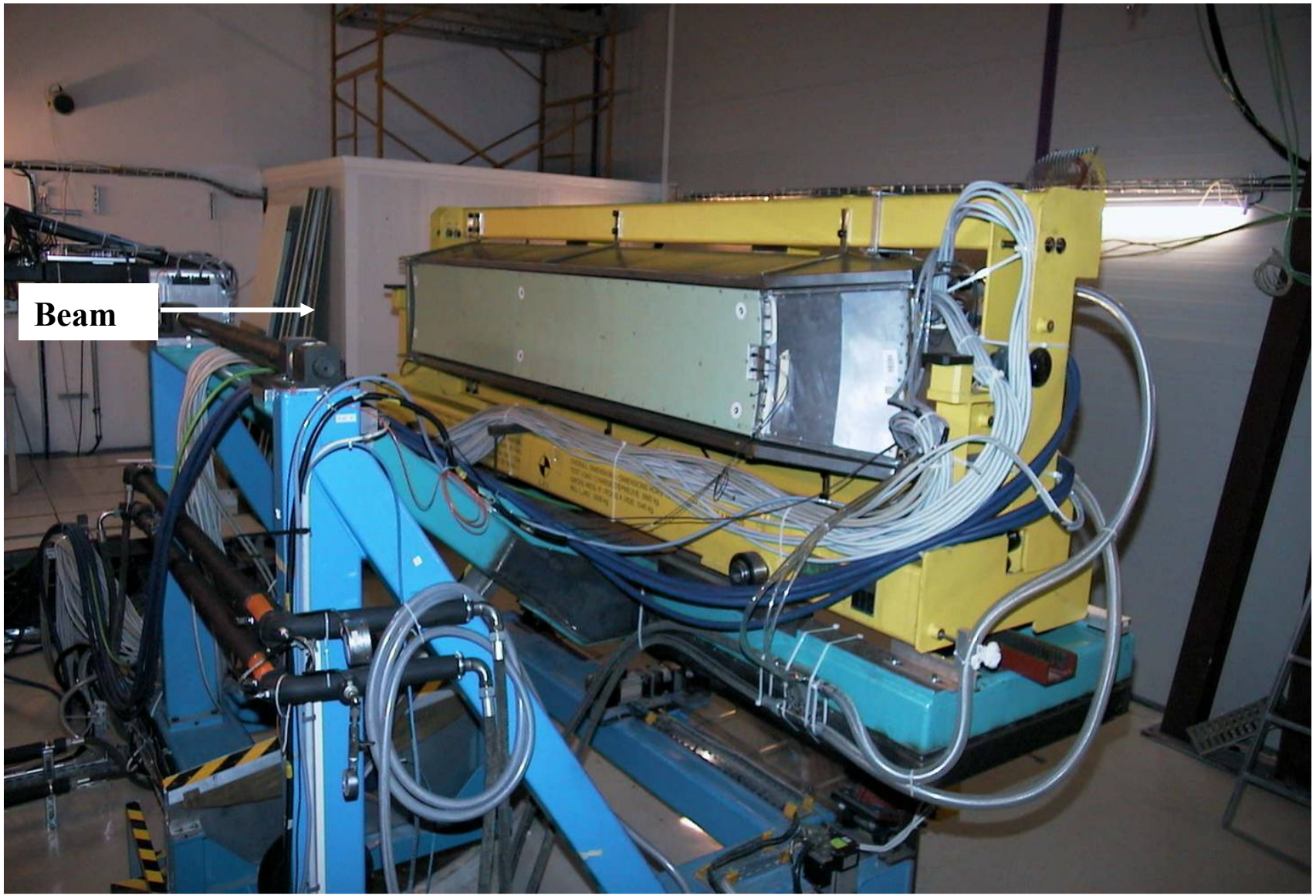
$$\frac{\sigma(E)}{E} = \frac{3\%}{\sqrt{E}} \oplus \frac{150\,MeV}{E} \oplus 0.40\%$$



ECAL


3.045 m
Barrel ECAL (EB)
1.290 m
61200 barrel crystals
14648 endcap crystals
Endcap ECAL (EE)
Preshower (SE)
η=1.479
η=1.653
η=2.6
η=3.0
y
z

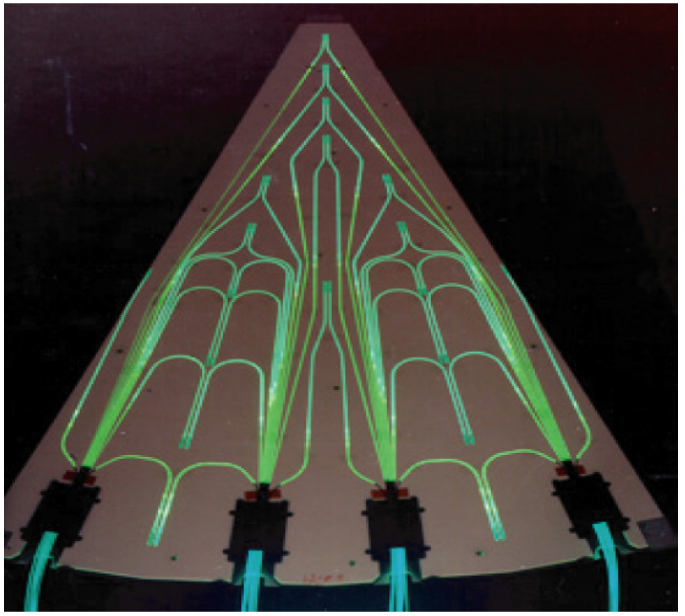
ECAL SM in Test Beam: Oct 04



The hadron calorimeter HCAL

CMS HCAL is constructed in 3 parts:

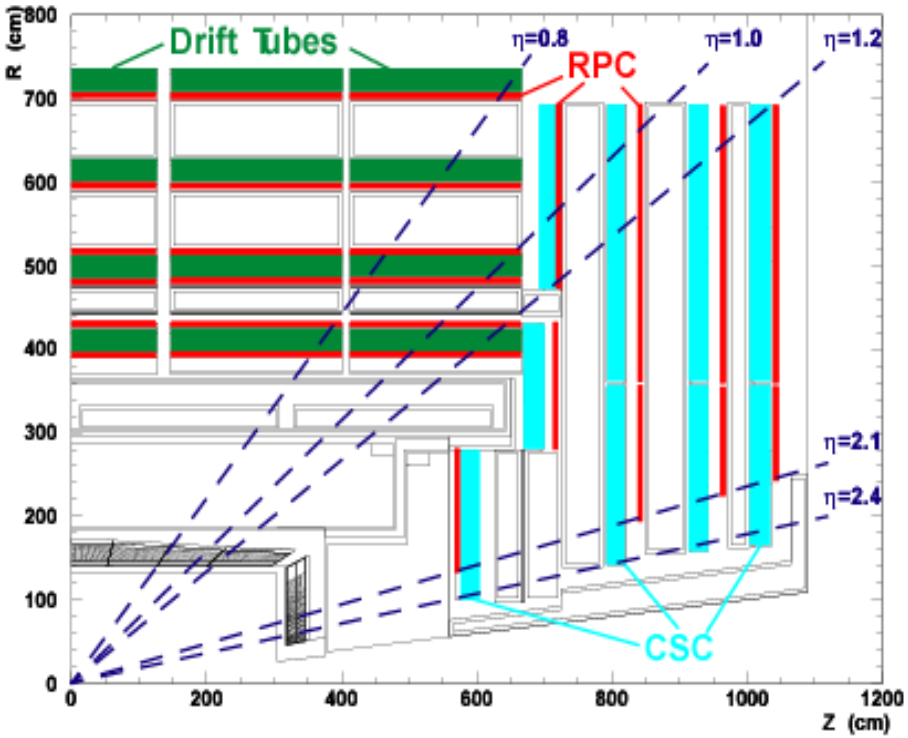
- Barrel HCAL (HB)
  - Brass plates interleaved wit plastic scintillator embedded with wavelength-shifting optical fibres (photo top right)
- Endcap HCAL (HE)
  - Brass plates interleaved with plastic scintillator
- Forward HCAL (HF)
  - Steel wedges stuffed with quartz fibres ~10000 channels total



Inside SX5 – the Hadron Calorimeter

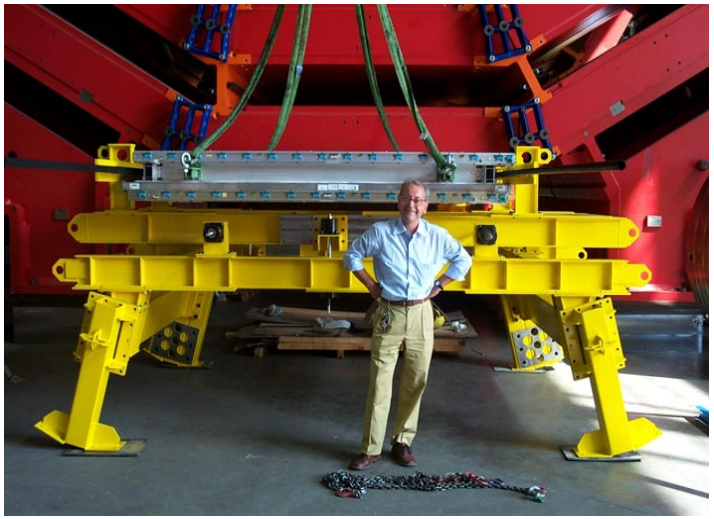
Photo of HCAL in SX5 – two half-barrels and two endcaps

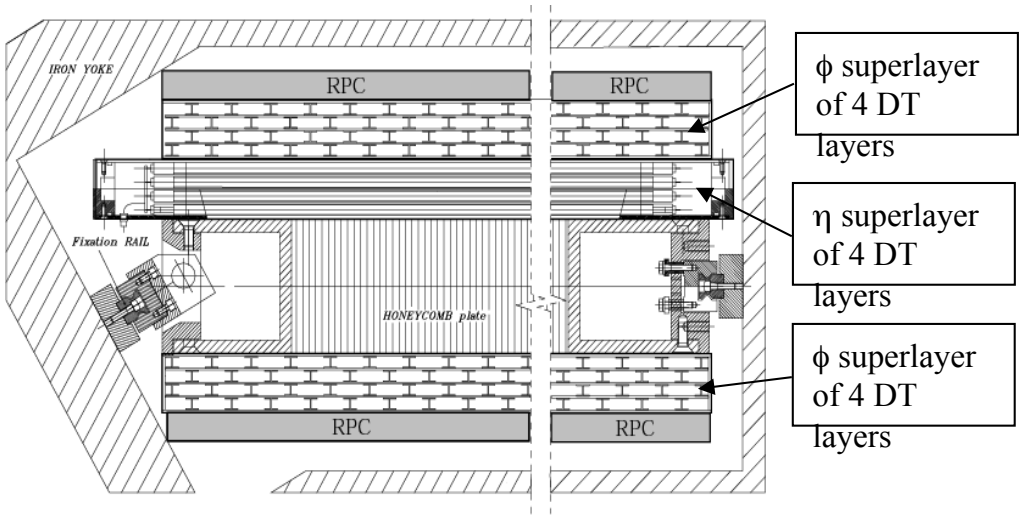
The Muon Chambers



Position measurement:
Drift Tubes (DT) in barrel
Cathode Strip Chambers (CSC) in endcaps

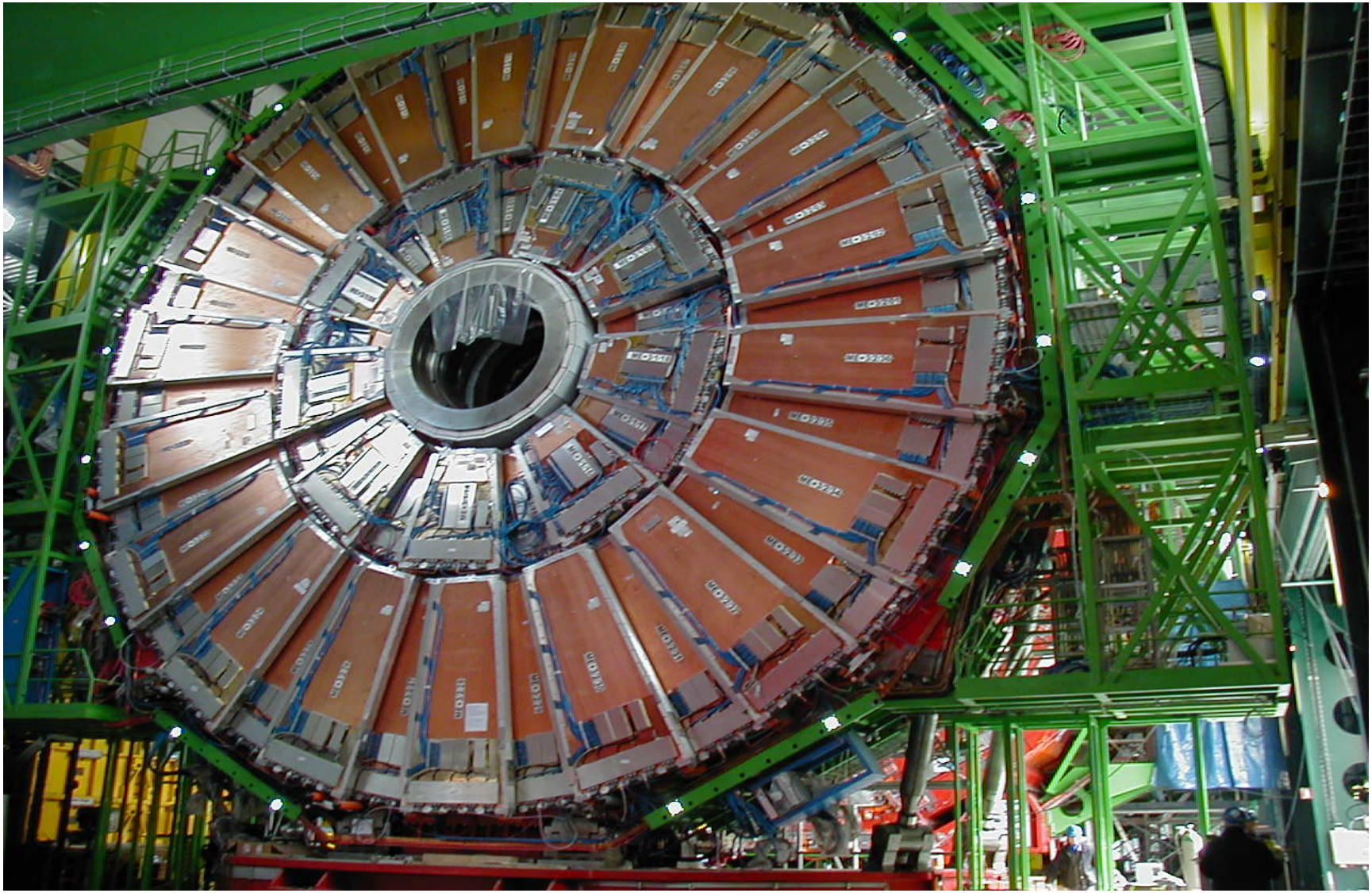
Trigger:
Resistive Plate Chambers (RPCs) in barrel and endcaps





195000 DT channels
210816 CSC channels
162282 RPC channels

Endcap Muons: CSCs at SX5

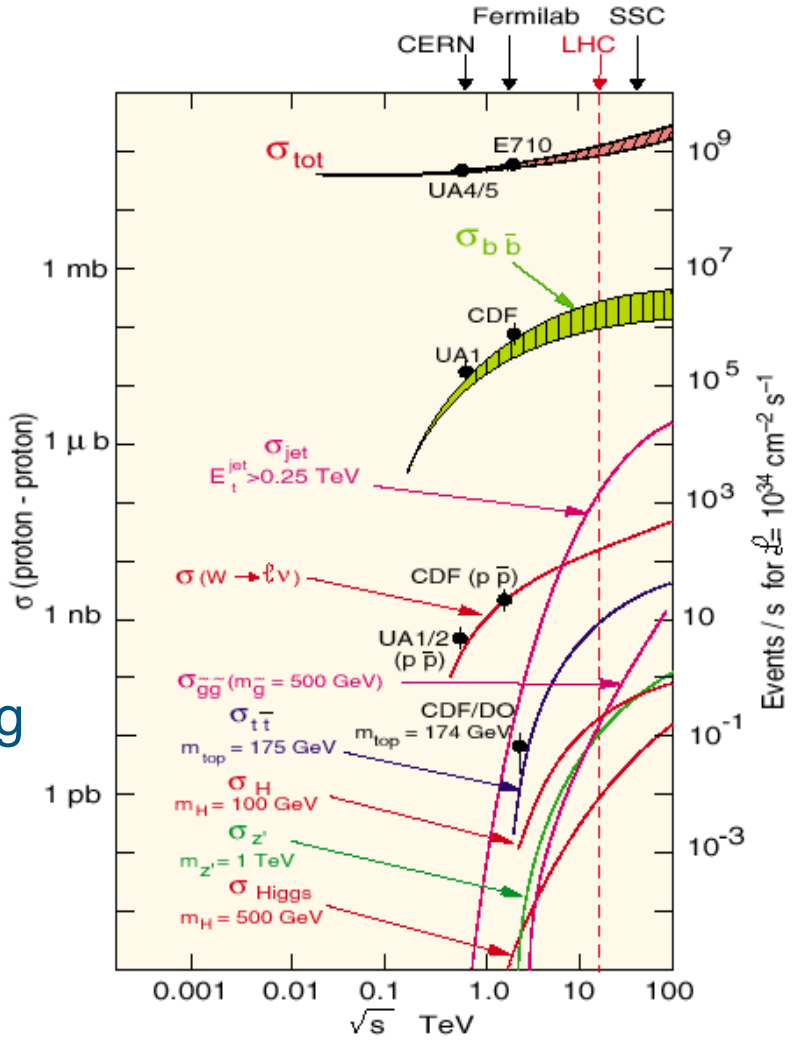


LHC cross sections and rates

At High Luminosity (10^{-33} cm^{-2} s^{-1})

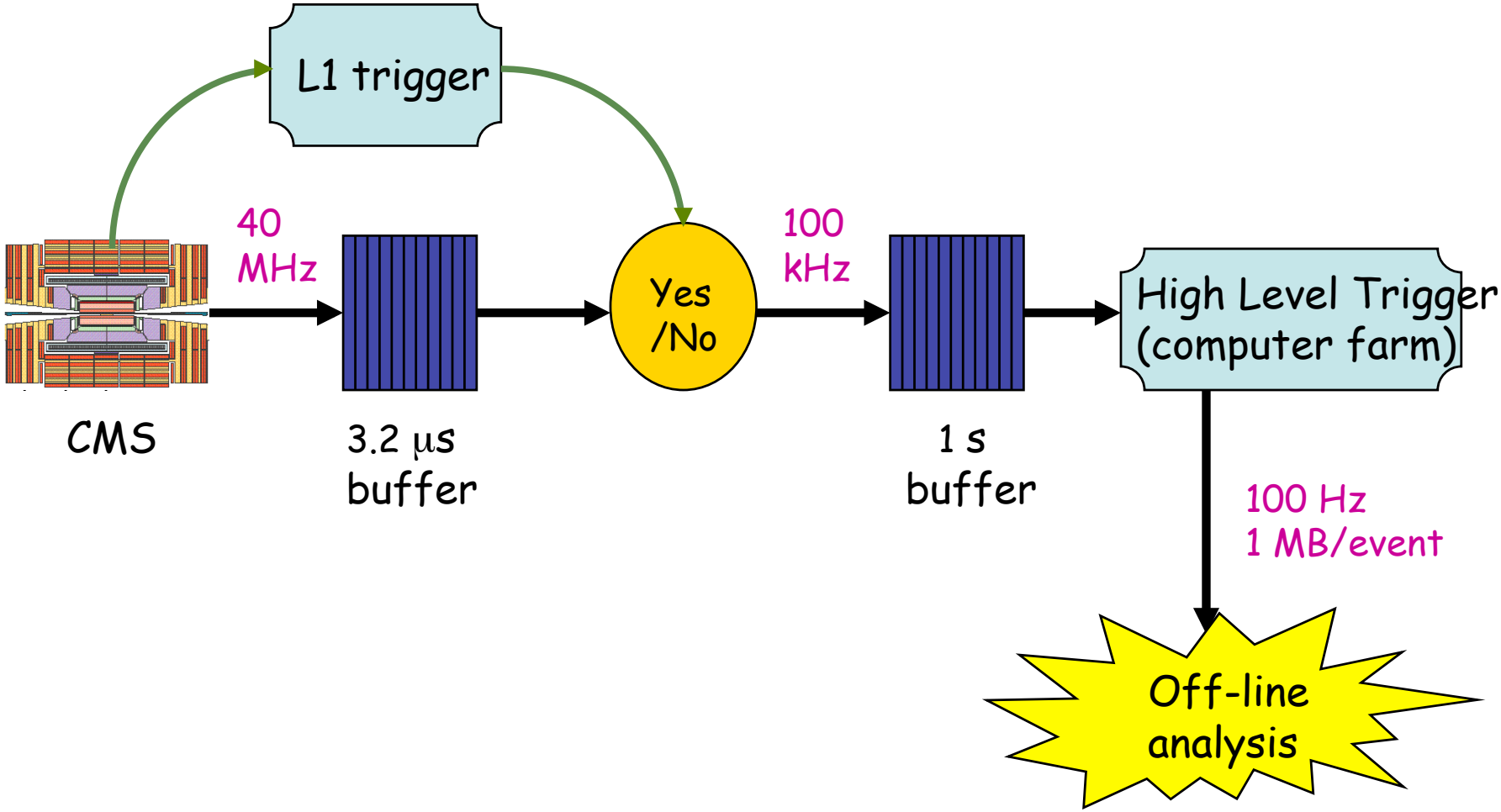
SM Higgs (125 GeV/c^2): →0.1 Hz
t t production: →1 Hz
W→ ℓ ν: →10 Hz
bb production: → 10^5 Hz
Inelastic: →10^8 Hz

Beam crossing every 50 ns
More than 20 pileup event / beam crossing

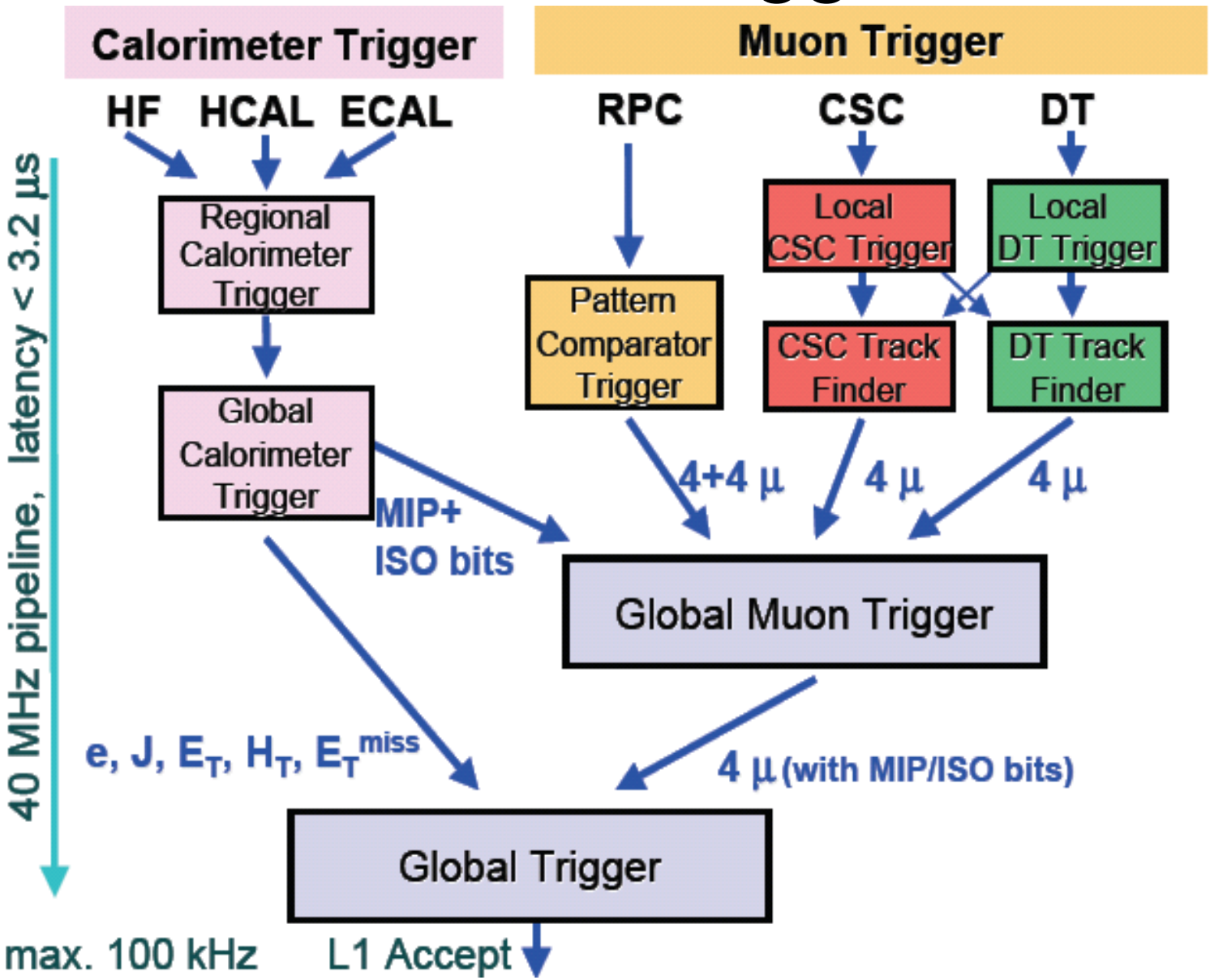


Trigger and DAQ

- Level 1 trigger based on muon & calorimeters ,
- then High Level trigger using reconstruction algorithms



Level-1 Trigger



Example of Trigger table

TRIGGER OBJECT			THRESHOLD (GeV)	RATE (Hz)
ISOLATED MUONS			19	25
DI-MUONS			7	4
ISOLATED ELECTRONS			29	33
ISOLATED DI-ELECTRONS			17	1
ISOLATED PHOTONS			80	4
ISOLATED DI-PHOTONS			40, 25	5
SINGLE JET, 3 JET, 4 JET			657, 247, 113	9
JET + MISSING ENERGY			180,123	5
TAU+ MISSING ENERGY				
INCLUSIVE TAU JET			86	3
DI-TAU JET			59	1
ELECTRON + JET			19, 45	2
INCLUSIVE B-JET			237	5
B-PHYSICS				
OTHERS (pre-scales, calibration)				10
TOTAL				105

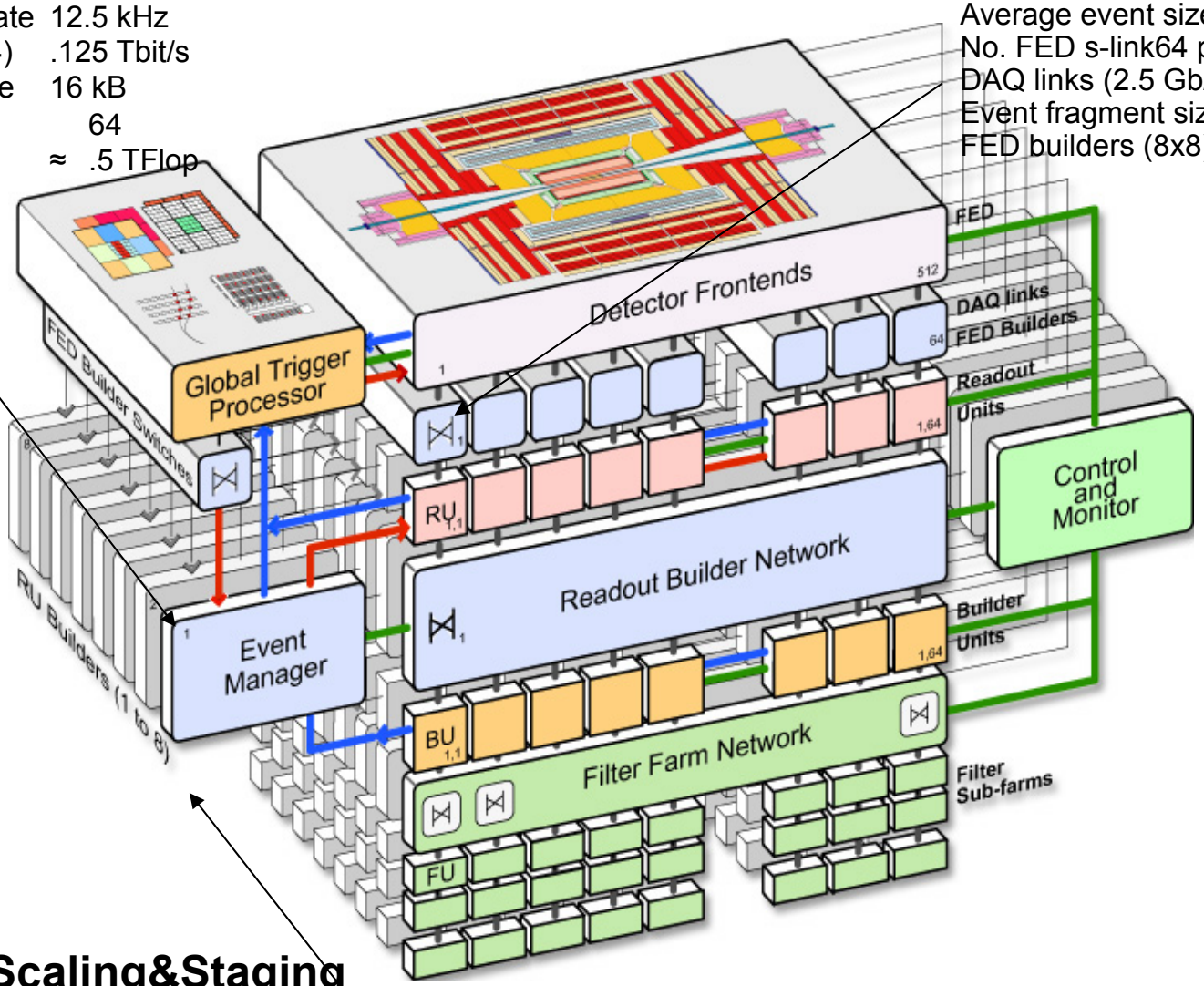
3D-EVB: scalable DAQ

DAQ unit (1/8th full system):

Lv-1 max. trigger rate	12.5 kHz
RU Builder (64x64)	.125 Tbit/s
Event fragment size	16 kB
RU/BU systems	64
Event filter power	≈ .5 TFlop

Data to surface:

Average event size		1 Mbyte
No. FED s-link64 ports	>	512
DAQ links (2.5 Gb/s)		512+512
Event fragment size		2 kB
FED builders (8x8)	≈	64+64

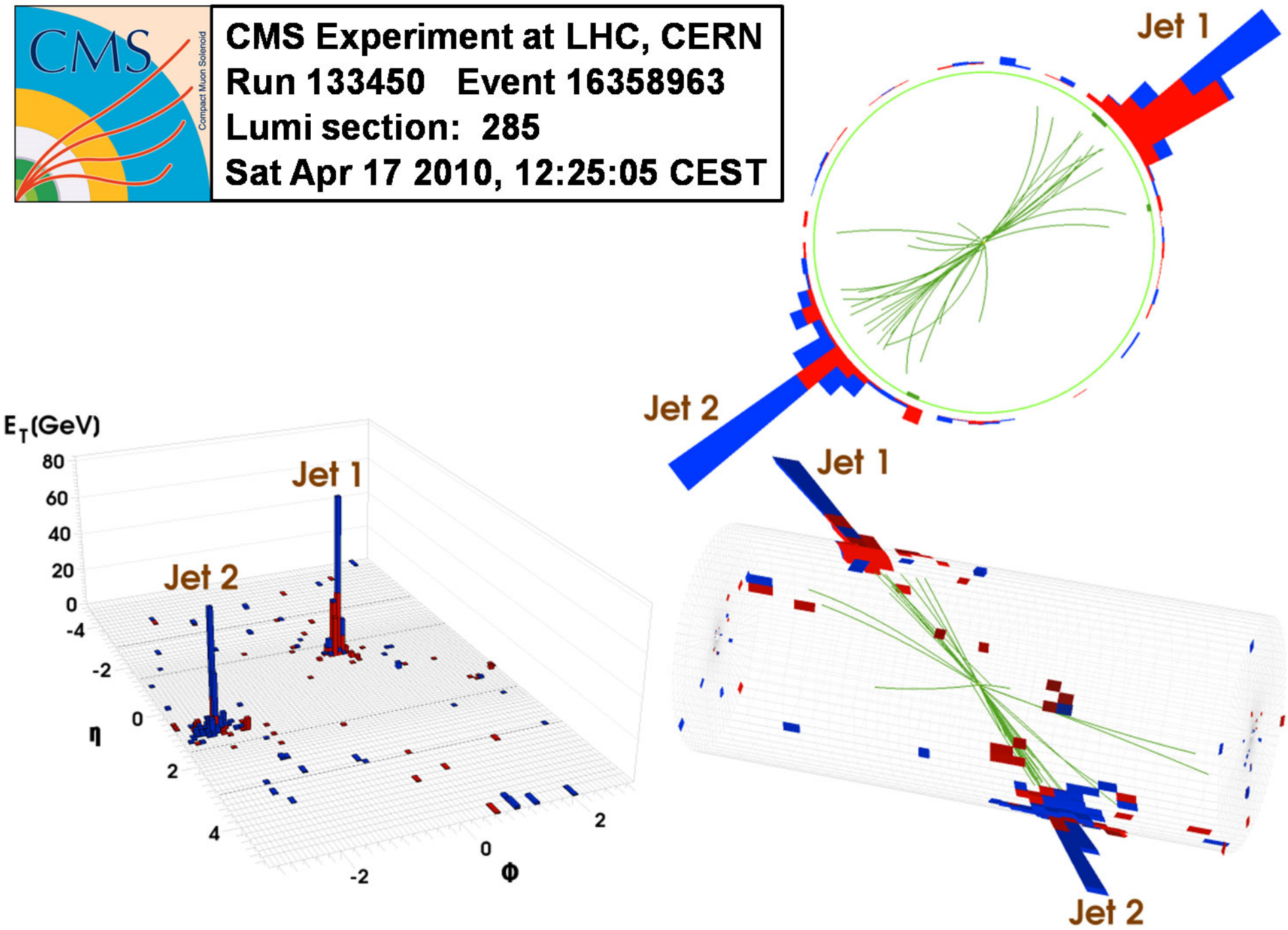


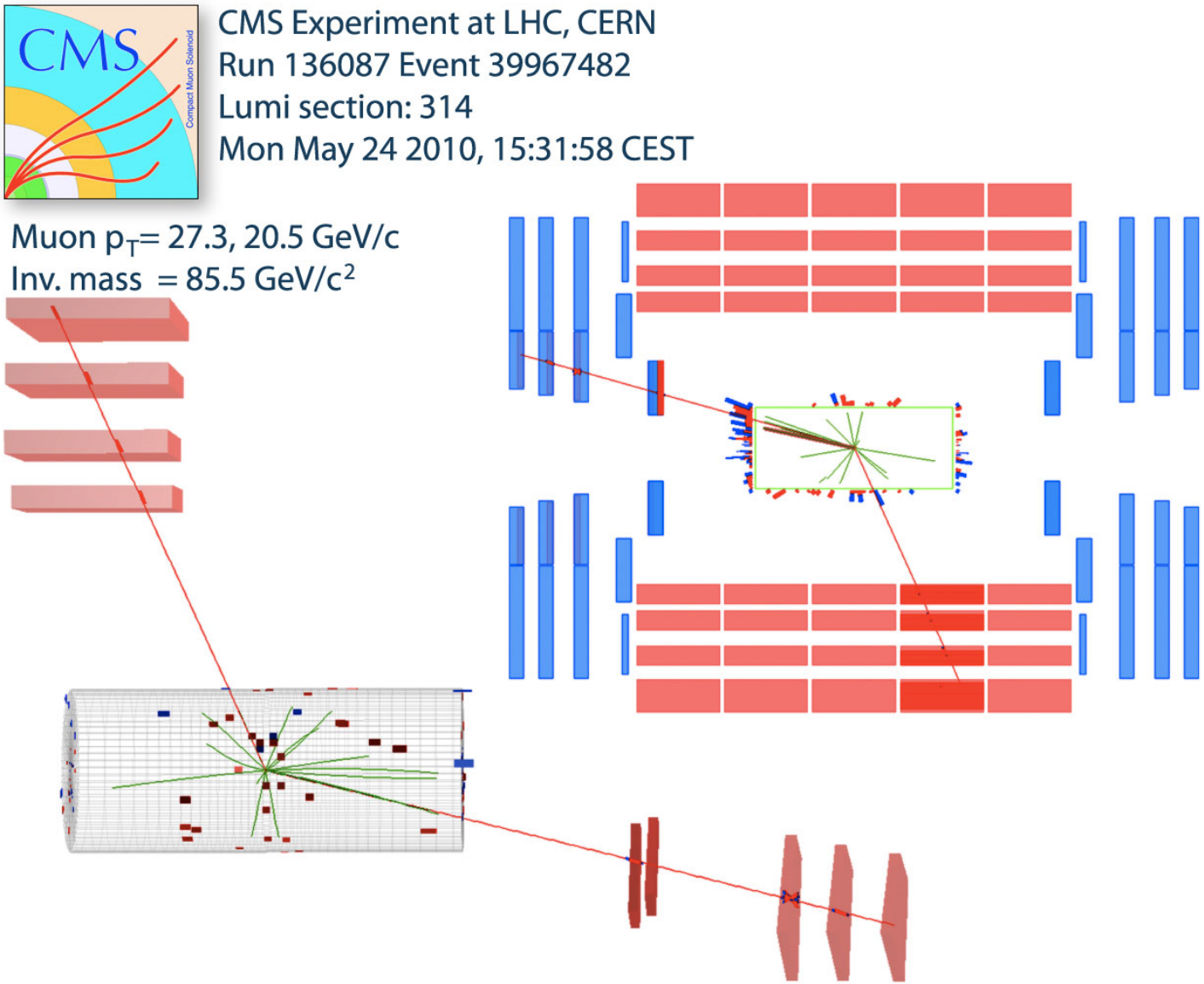
DAQ Scaling&Staging

CMS Collaboration and the LHC Computing Grid

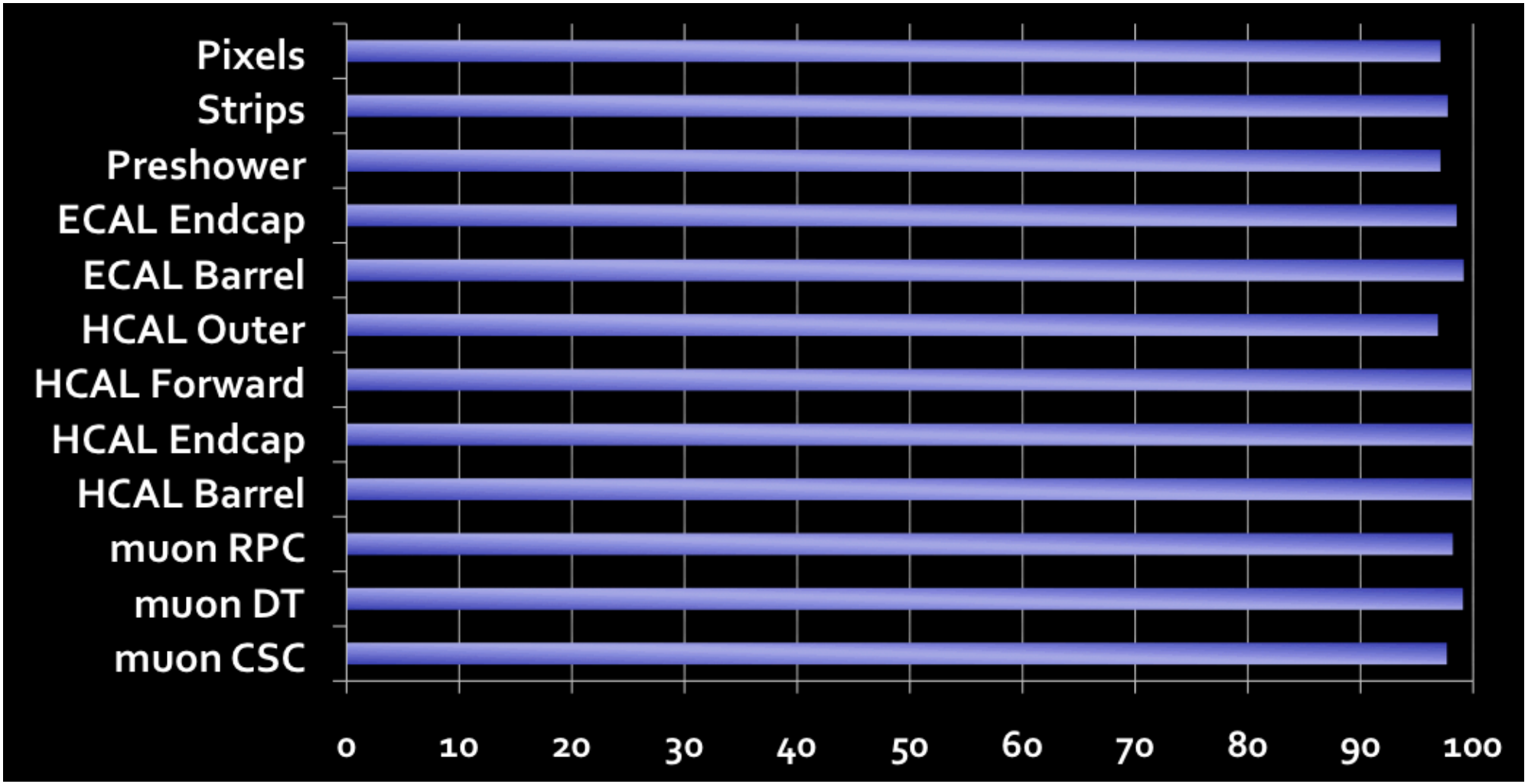
CMS Collaboration

- 179 institutes in 41 countries
- 3,300 physicists incl. 1,500 students
- 790 engineers and support staff

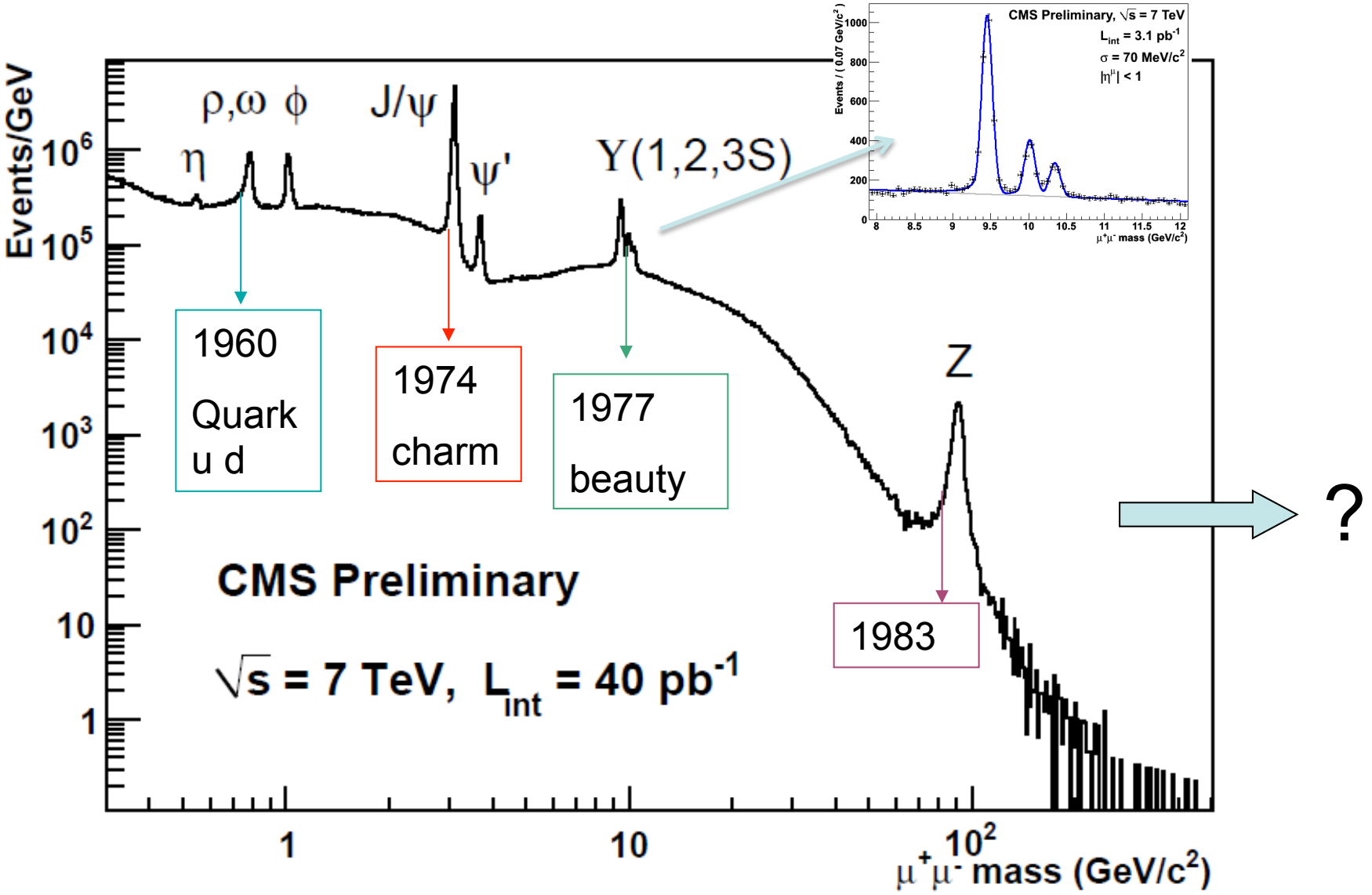

CMS
Compact Muon Solenoid
CMS Experiment at LHC, CERN
Run 133450 Event 16358963
Lumi section: 285
Sat Apr 17 2010, 12:25:05 CEST
Jet 1
Jet 2
E_T(GeV)
80
60
40
20
0
-4
-2
0
2
4
η
-2
0
2
Φ
Jet 1
Jet 2
Jet 1
Jet 2

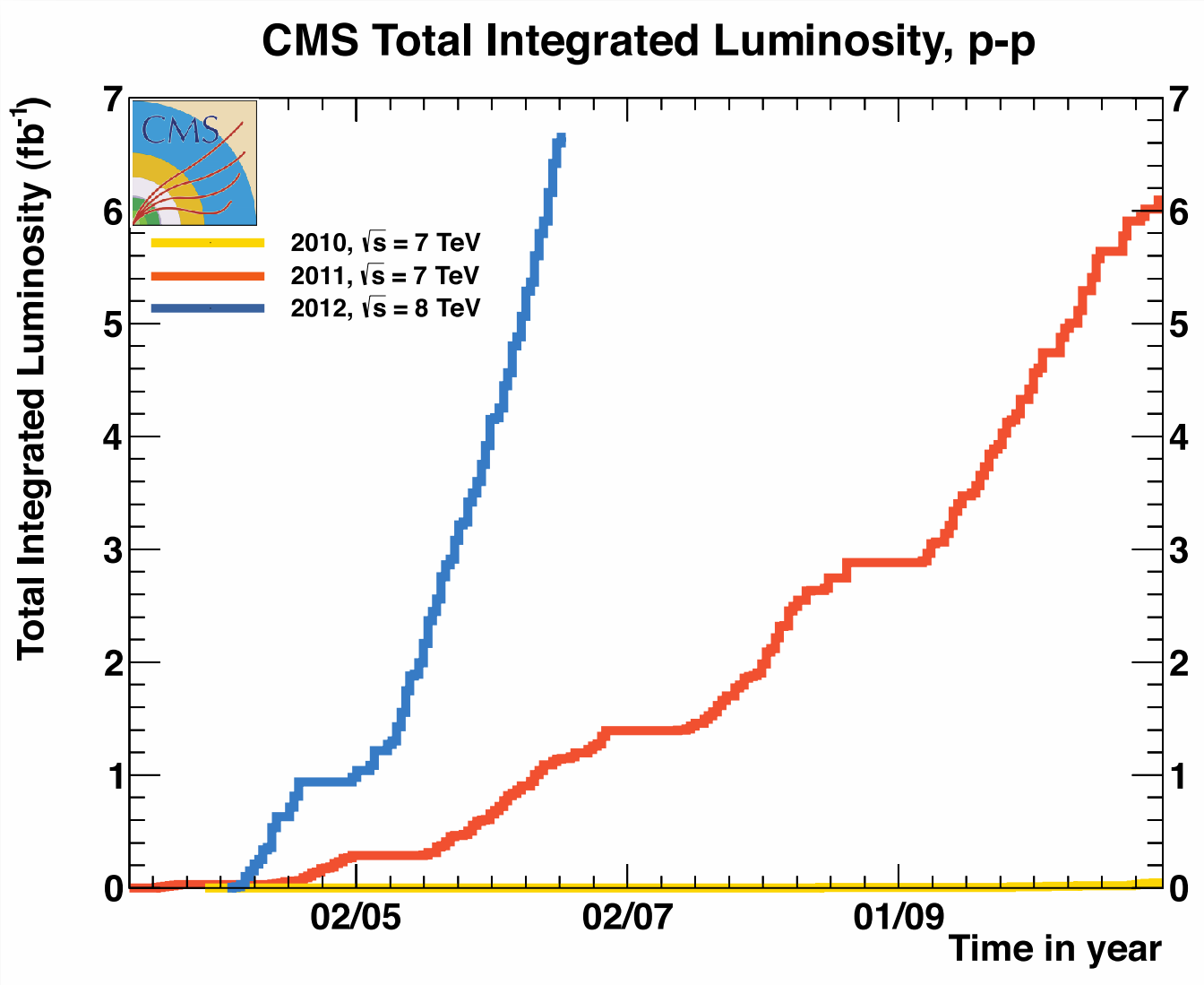

CMS
Compact Muon Solenoid
CMS Experiment at LHC, CERN
Run 136087 Event 39967482
Lumi section: 314
Mon May 24 2010, 15:31:58 CEST
Muon p_T= 27.3, 20.5 GeV/c
Inv. mass = 85.5 GeV/c^2

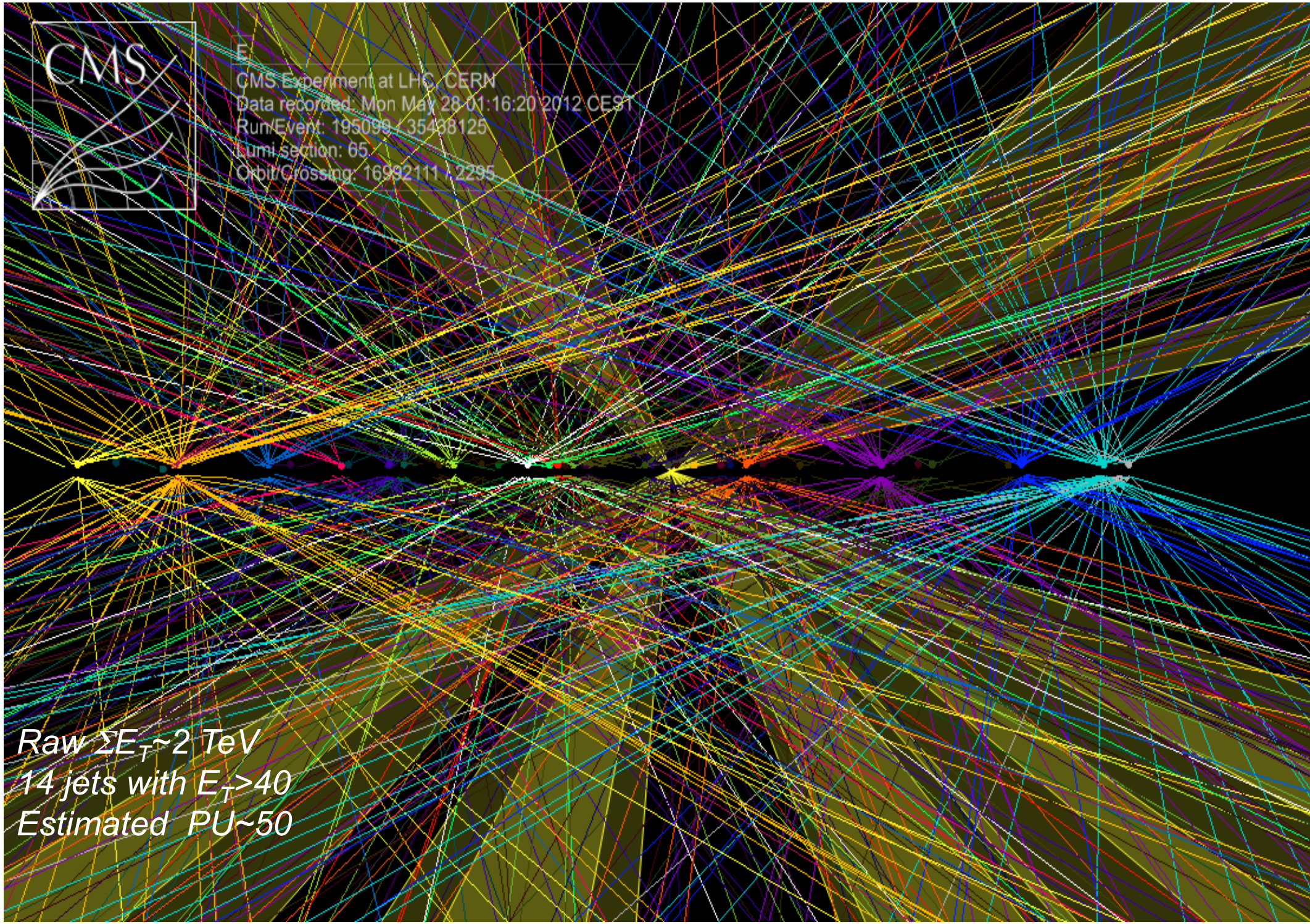
Current operational status of CMS June 2012



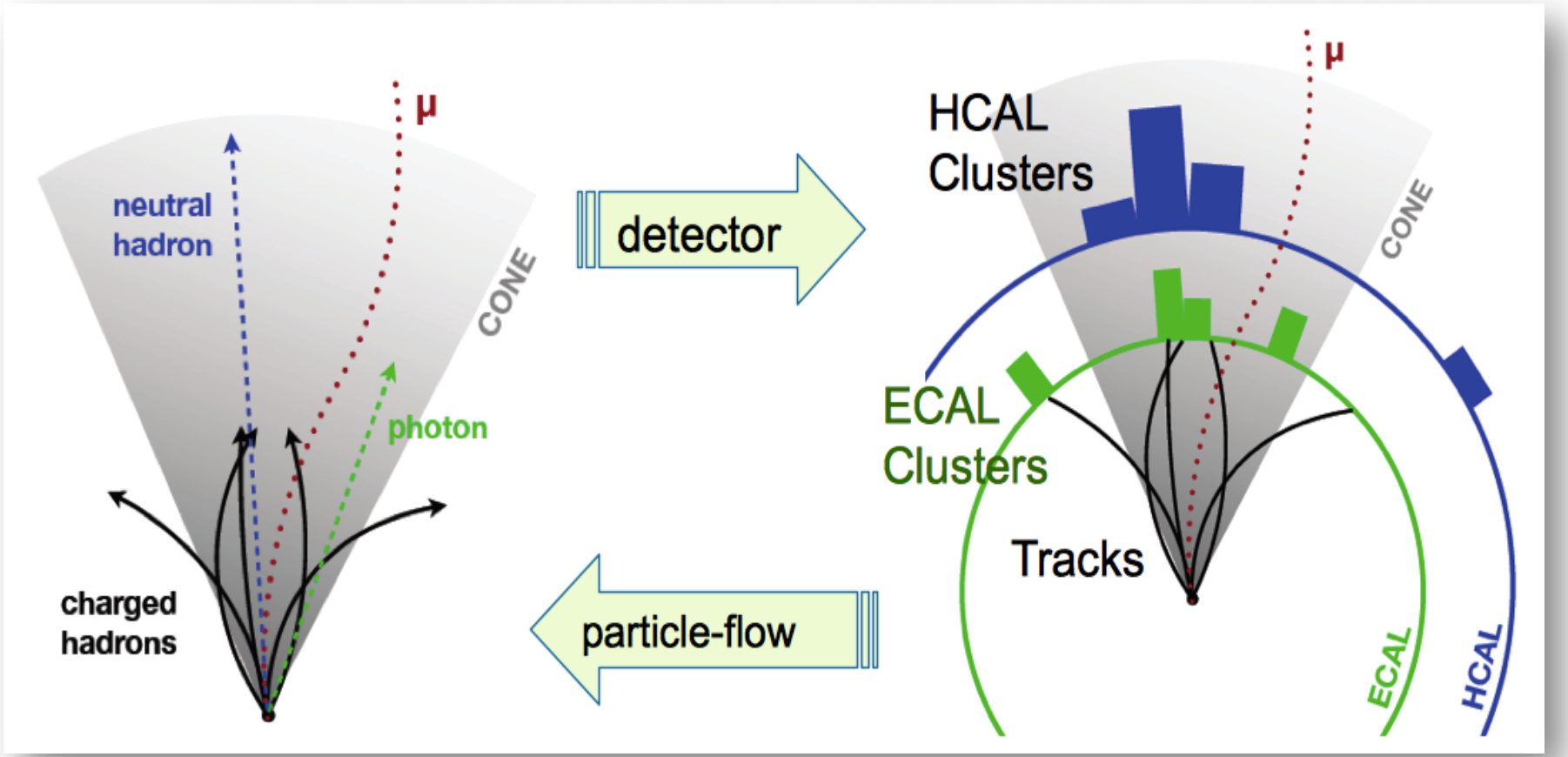
Rediscovered the Standard Model in 2010: example μ+μ- inv mass spectrum



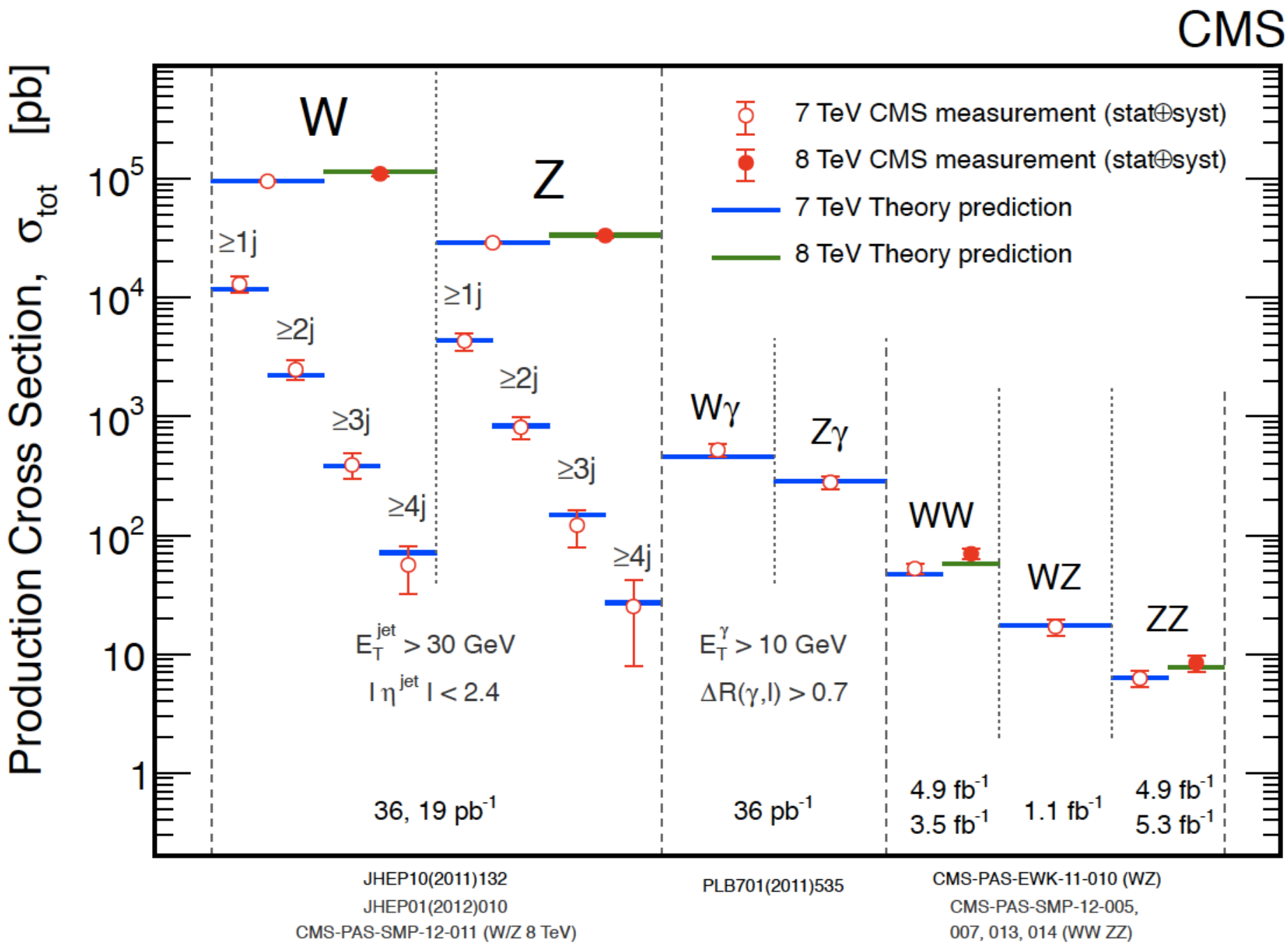

CMS Total Integrated Luminosity, p-p
Total Integrated Luminosity (fb-1)
CMS
2010, √s = 7 TeV
2011, √s = 7 TeV
2012, √s = 8 TeV
0
1
2
3
4
5
6
7
02/05
02/07
01/09
Time in year


CMS
CMS Experiment at LHC, CERN
Data recorded: Mon May 28 01:16:20 2012 CEST
Run/Event: 195099 / 35438125
Lumi section: 65
Orbit/Crossing: 16992111 / 2295
Raw ΣE$_T$~2 TeV
14 jets with E$_T$>40
Estimated PU~50

Particle-reconstruction techniques (Particle Flow)



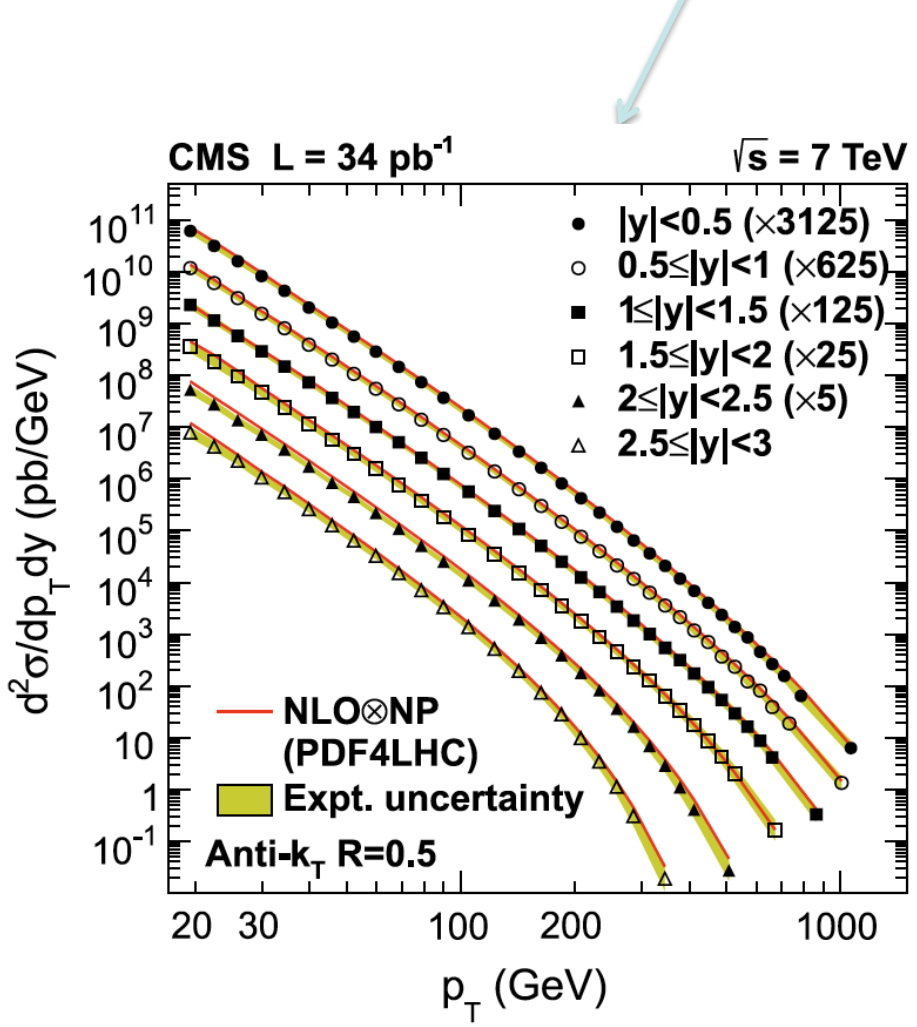
.

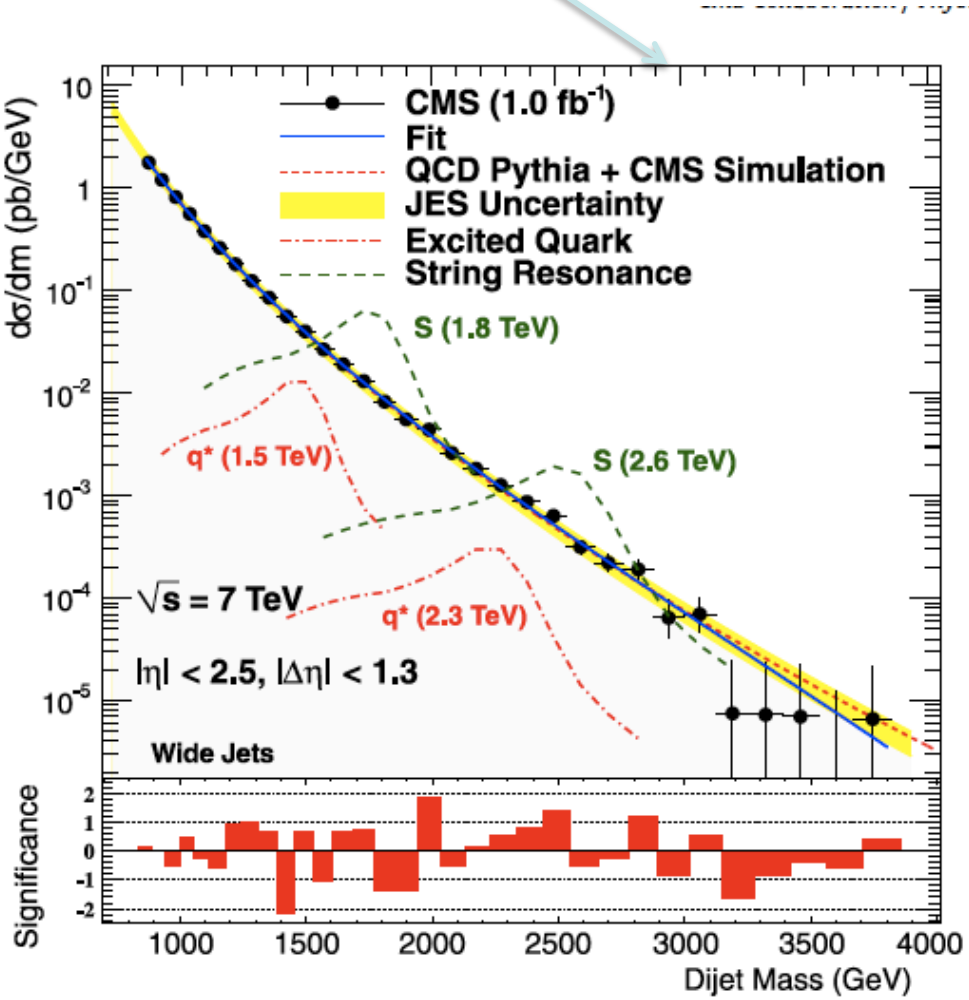

CMS
Production Cross Section, σ_{tot} [pb]
10^5
10^4
10^3
10^2
10
1
W
Z
≥1j
≥2j
≥3j
≥4j
≥1j
≥2j
≥3j
≥4j
Wγ
Zγ
WW
WZ
ZZ
7 TeV CMS measurement (stat⊕syst)
8 TeV CMS measurement (stat⊕syst)
7 TeV Theory prediction
8 TeV Theory prediction
$E_T^{jet} > 30$ GeV
$|\eta^{jet}| < 2.4$
$E_T^{\gamma} > 10$ GeV
$\Delta R(\gamma,l) > 0.7$
36, 19 pb^{-1}
36 pb^{-1}
4.9 fb^{-1}
3.5 fb^{-1}
1.1 fb^{-1}
4.9 fb^{-1}
5.3 fb^{-1}
JHEP10(2011)132
JHEP01(2012)010
CMS-PAS-SMP-12-011 (W/Z 8 TeV)
PLB701(2011)535
CMS-PAS-EWK-11-010 (WZ)
CMS-PAS-SMP-12-005,
007, 013, 014 (WW ZZ)

PRL 107 (2011) 132001

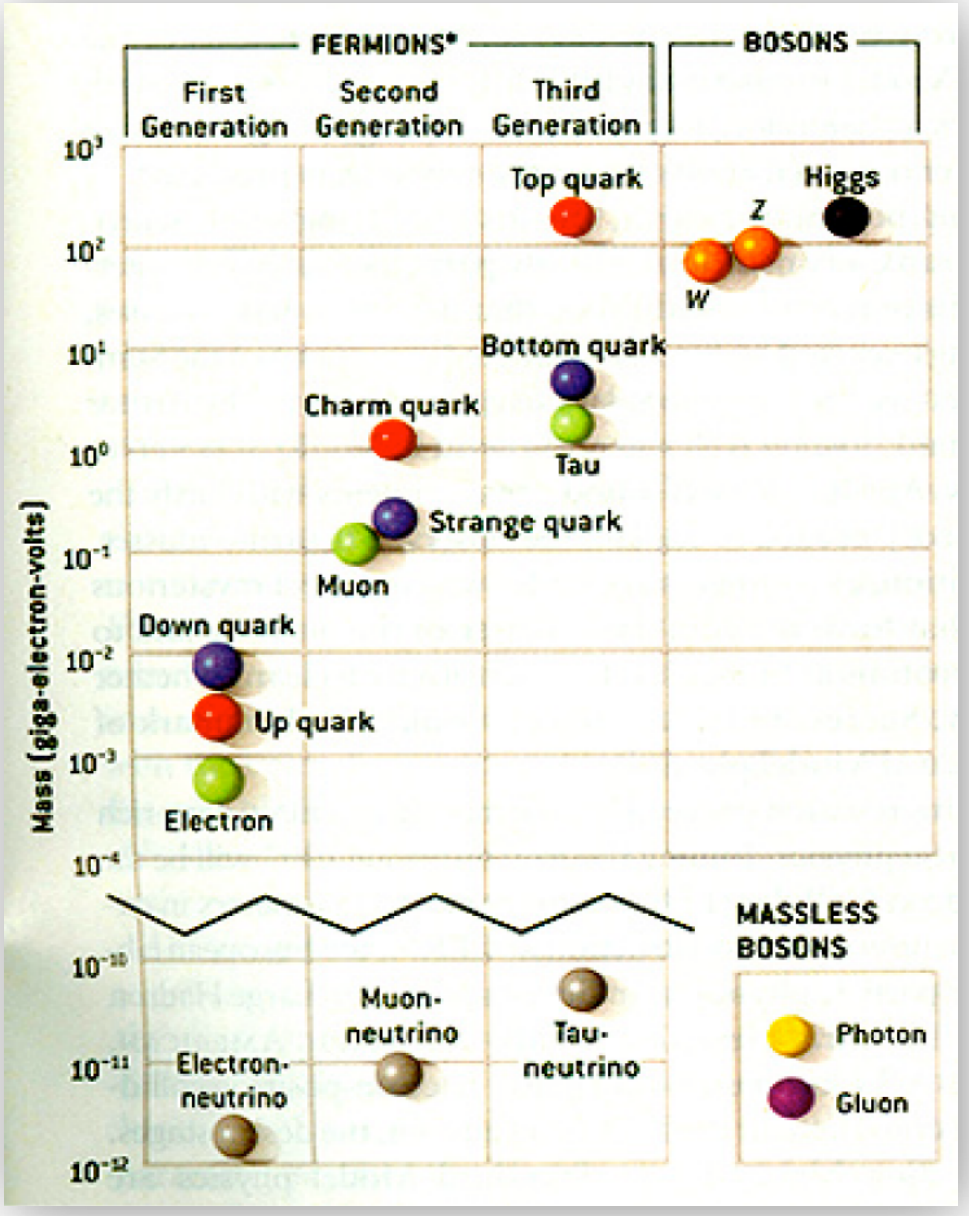
PLB 704 (2011) 23

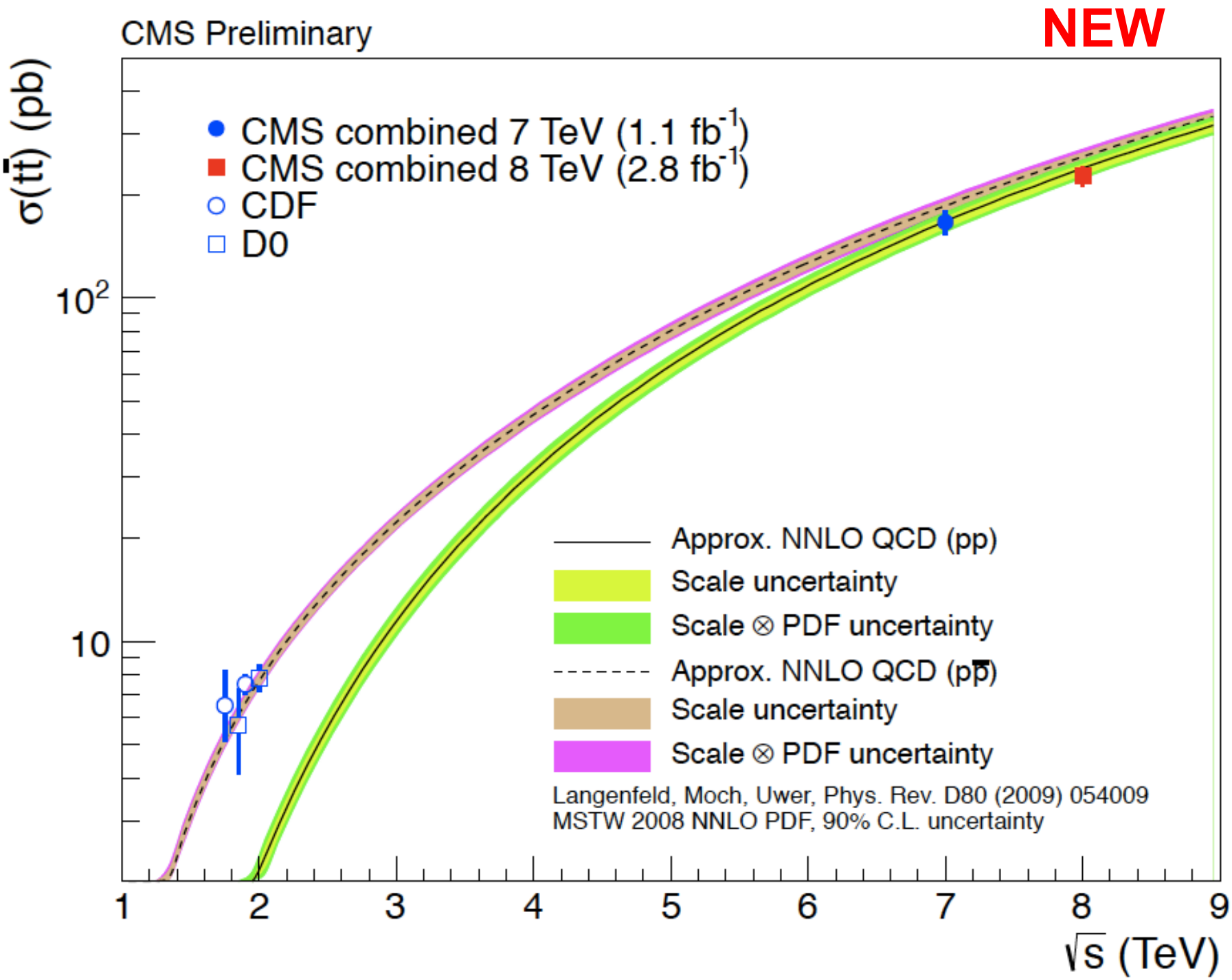
Production of jets: inclusive and di-jets





The top quark



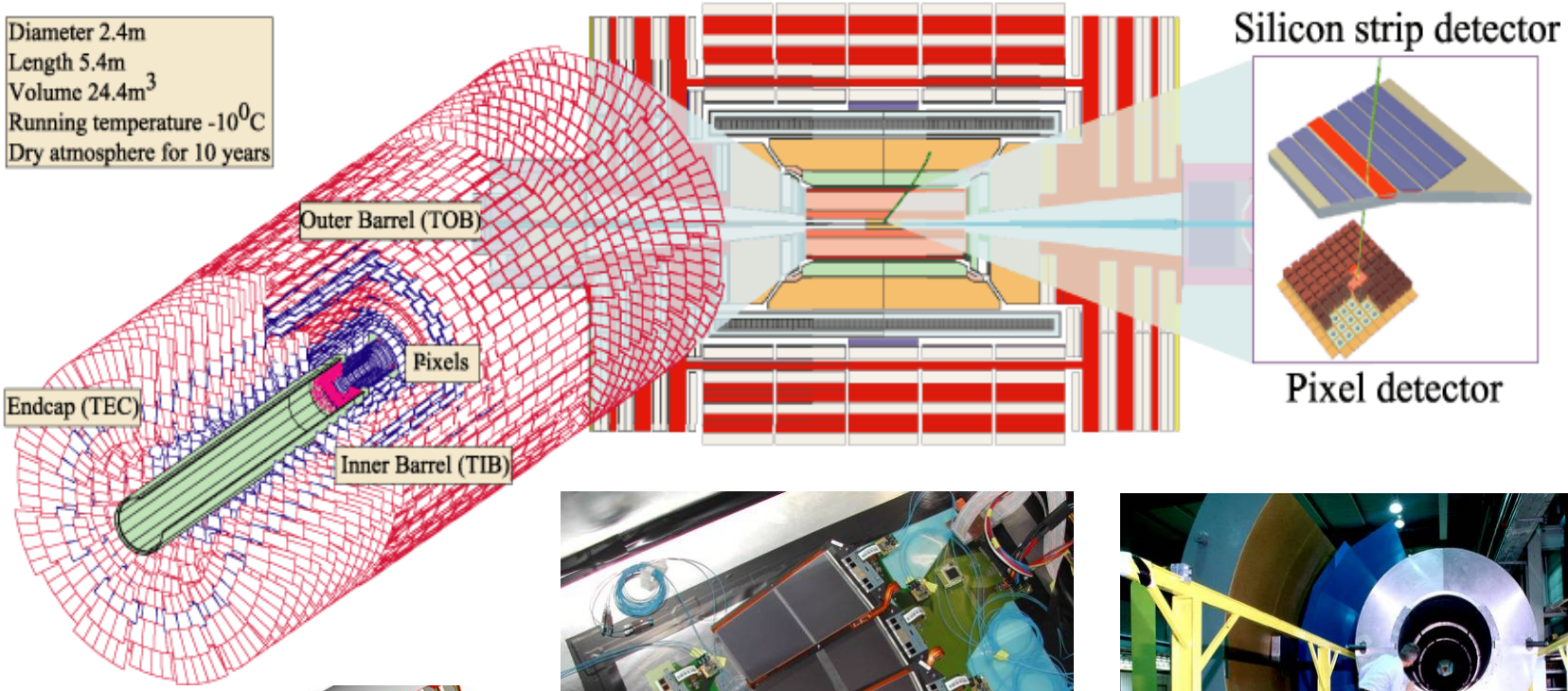

CMS Preliminary
NEW
σ(tt̄) (pb)
CMS combined 7 TeV (1.1 fb-1)
CMS combined 8 TeV (2.8 fb-1)
CDF
D0
Approx. NNLO QCD (pp)
Scale uncertainty
Scale ⊗ PDF uncertainty
Approx. NNLO QCD (pp̄)
Scale uncertainty
Scale ⊗ PDF uncertainty
Langenfeld, Moch, Uwer, Phys. Rev. D80 (2009) 054009
MSTW 2008 NNLO PDF, 90% C.L. uncertainty
10
10^2
1
2
3
4
5
6
7
8
9
√s (TeV)

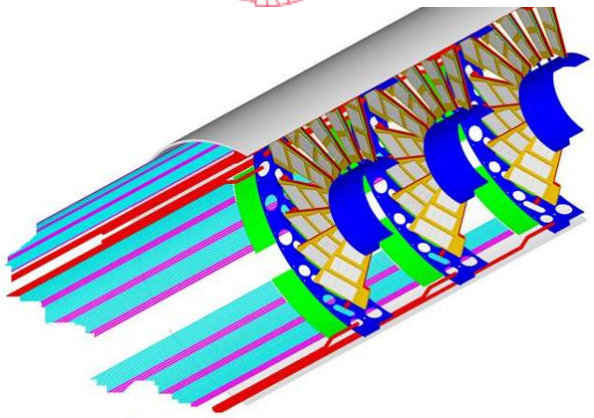
Final Comments

- We are living exciting days, Standard Model measurements are the pillars under this excitement …
- We have investigated in great detail W,Z, Top and jet production in the first 2.5 years and went well beyond the simple “rediscovery”
- The experiment is in the era of the Higgs and beyond …

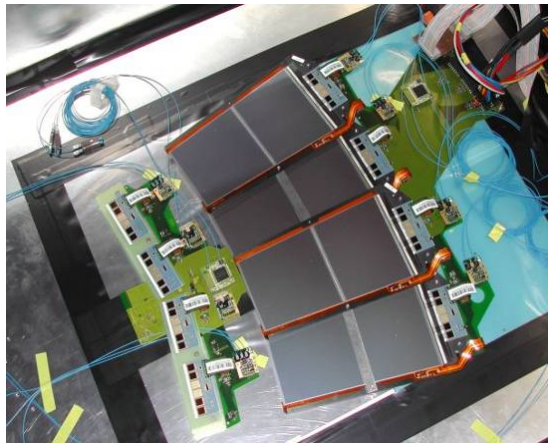
Backup Slides

The Tracker



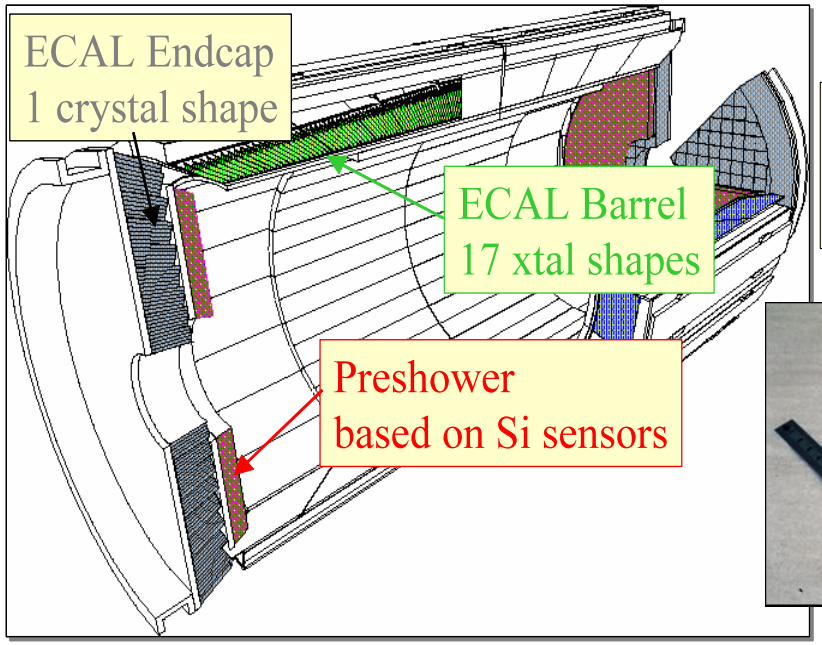


Pixel endcap disks

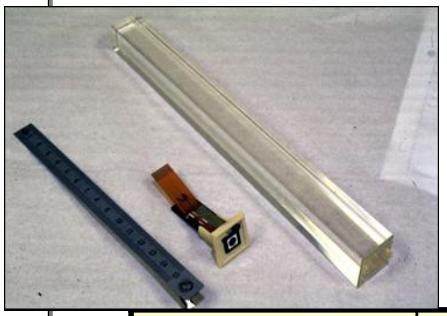


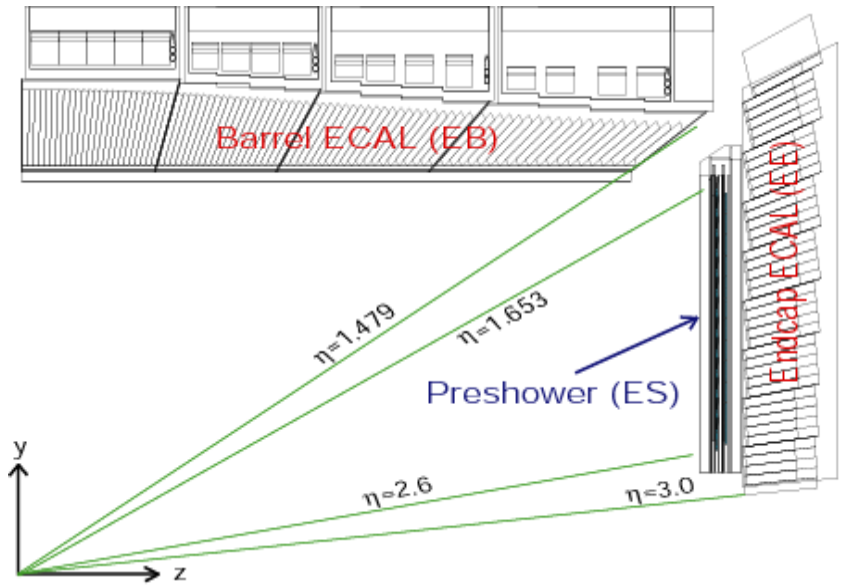
207m^2 of silicon sensors
10.6 million silicon strips
65.9 million pixels in final configuration!

ECAL



Characteristics of $PbWO_4$
X_0 = 0.89cm
ρ = 8.28g/cm^3
R_M (Molière radius) = 2.2cm

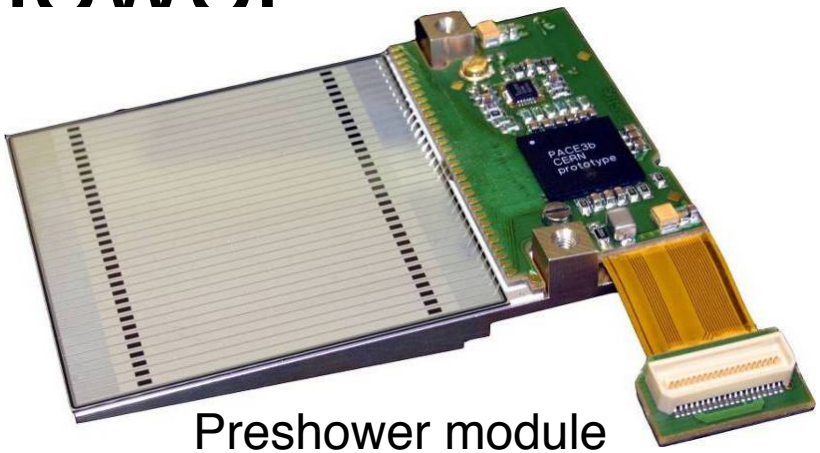




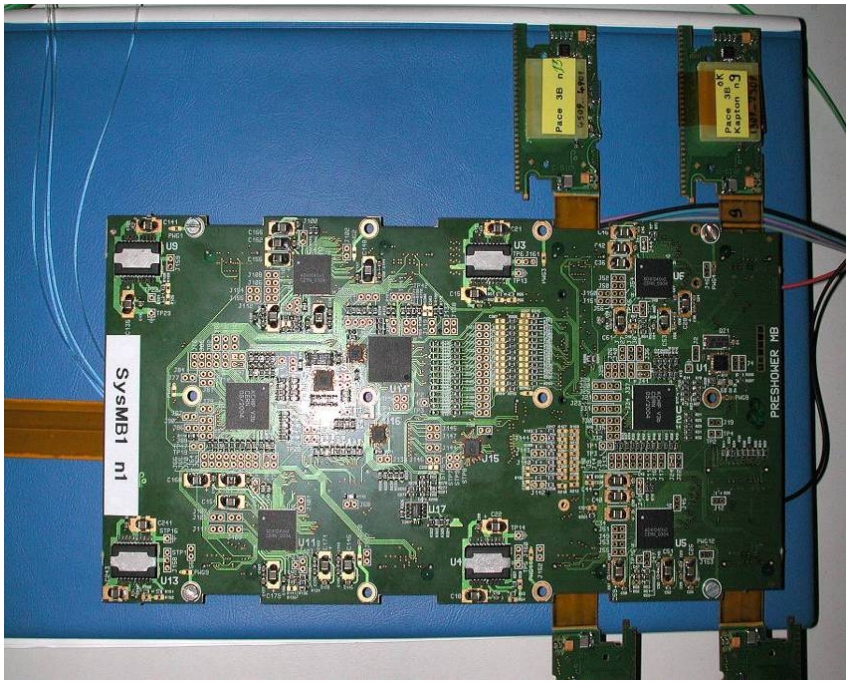
Parameter	Barrel	Endcaps
Coverage	**$\|\eta\|<1.48$**	**$1.48<\|\eta\|<3.0$**
$\Delta\phi$ x $\Delta\eta$	**0.0175 x 0.0175**	**0.0175 x 0.0175 to 0.05 x 0.05**
Depth in X_0	**25.8**	**24.7**
# of crystals	**61200**	**14648**
Volume	**8.14m^3**	**2.7m^3**
Xtal mass (t)	**67.4**	**22.0**

ES : Preshower

- Silicon Sensor production nearly completed (>90%)
- PACE3 chipset submitted for production
  - Successful engineering run : 560 packaged ASICS tested with 80% yield
- System tested in beam
  - S/N ratio at mip > 7 in high (calibration) gain
- Pre-production of hybrids started in Greece



Preshower module



System Mother Board